This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.
+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.
+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.
+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`

THE SOCIETY OF AUTOMOTIVE ENGINEERS

INC.

1919

TRANSACTIONS

PART I

Digitized by Google

Library
of the
University of Wisconsin

Digitized by Google

Digitized by Google

Digitized by Google

TRANSACTIONS OF THE

SOCIETY OF AUTOMOTIVE ENGINEERS

INC.

PART I VOLUME XIV 1919

Papers and Reports Presented at Society and Section Meetings

Copyright, 1920, by the
Society of Automotive Engineers, Inc.

OFFICE OF THE SOCIETY
29 W. 39TH STREET, NEW YORK CITY

Digitized by Google

The Society of Automotive Engineers
INC.

Founded 1905 — Incorporated 1909

PAST PRESIDENTS

1905-1907.....Andrew L Riker
1908.....Thomas J Fay
1909.....Henry Hess
1910.....Howard E Coffin
1911.....Henry Souther (deceased)
1912.....Henry F Donaldson (deceased)
1912.....Herbert W Alden
1913.....Howard Marmon
1914.....Henry M Leland
1915.....W H Vandervoort
1916.....Russell Huff
1917.....George W Dunham
1918 .....Charles F Kettering

The Society shall not be responsible for statements or opinions advanced in papers or discussions at its meetings * * *
—(*Constitution, paragraph* 54)

Digitized by Google

237171
SEP 22 1920
S
·S06
14
1

OFFICERS OF THE SOCIETY

President, Charles M Manly, New York City
First Vice-President, B B Bachman, Ardmore, Pa
Second Vice-President, E H Belden, Toledo, Ohio
(Representing Motor Car Engineering)
Second Vice-President, E A Sperry, Brooklyn, N Y
(Representing Aviation Engineering)
Second Vice-President, J. J Amory, New York City
(Representing Marine Engineering)
Second Vice-President, T B Funk, Rock Island, Ill
(Representing Tractor Engineering)
Second Vice-President, L S Keilholtz, Dayton, Ohio
(Representing Stationary Internal-Combustion Engineering)
Treasurer, C B Whittelsey, Hartford, Conn
Chairman of Finance Committee, Horace M Swetland, New York City
Chairman of Standards Committee, B B Bachman, Ardmore, Pa
Secretary and General Manager, Coker F Clarkson, New York City

MEMBERS OF THE COUNCIL

Charles M Manly, New York City
B B Bachman, Ardmore, Pa
E H Belden, Toledo, Ohio
E A Sperry, Brooklyn, N Y
J J Amory, New York City
T B Funk, Rock Island, Ill
L S Keilholtz, Dayton, Ohio
E A DeWaters, Flint, Mich
David Fergusson, Buffalo, N Y
E A Johnston, Chicago, Ill
Charles S Crawford, Indianapolis, Ind
J V Whitbeck, Cleveland, Ohio
D Beecroft, New York City
C B Whittelsey, Hartford, Conn
C F Kettering, Dayton, Ohio (Past-President)

Digitized by Google

SECTIONS OF THE SOCIETY

BUFFALO SECTION

E T MATHEWSON ..... *Chairman*
HUGH R CORSE ..... *Vice-chairman*
HARRY HOUSE, JR. ..... *Treasurer*
ROGER CHAUVEAU ..... *Secretary*
(Address) 1100 Military Road, Buffalo, N. Y.

CLEVELAND SECTION

H C SNOW ..... *Chairman*
H H NEWSOM ..... *Vice-chairman*
K B BRITTON ..... *Treasurer*
A E JACKMAN ..... *Secretary*
(Address) 1900 Euclid Avenue, Cleveland, Ohio

DETROIT SECTION

W A BRUSH ..... *Chairman*
E G GUNN ..... *Vice-chairman*
E W SEAHOLM ..... *Treasurer*
R H SHERRY ..... *Secretary*
(Address) 1033 Book Building, Detroit, Mich.

INDIANA SECTION

D L GALLUP ..... *Chairman*
STANLEY WHITWORTH ..... *Vice-chairman*
W S REED ..... *Secretary and Treasurer*
(Address) 1602 Merchants Bank Building, Indianapolis, Ind.

Digitized by Google

METROPOLITAN SECTION

A C Bergmann ..... *Chairman*
C F Scott ..... *Vice-chairman*
L G Nilson ..... *Treasurer*
A M Wolf ..... *Secretary*
(Address) 114 East Sixteenth Street, New York City

MID-WEST SECTION

Dent Parrett ..... *Chairman*
G W Smith ..... *Vice-chairman*
Francis W. Parker, Jr. ..... *Treasurer*
C S Rieman ..... *Secretary*
(Address) Sixty-first Street and Archer Avenue, Argo, Ill.

MINNEAPOLIS SECTION

J L Mowry ..... *Chairman*
A W Scarratt ..... *Vice-chairman*
J S Clapper ..... *Treasurer*
C T Stevens ..... *Secretary*
(Address) 13 South Ninth Street, Minneapolis, Minn.

PENNSYLVANIA SECTION

A K Brumbaugh ..... *Chairman*
C A Musselman ..... *Vice-chairman*
W H Sackman ..... *Treasurer*
G W Smith, Jr. ..... *Secretary*
(Address) 309 Hillside Avenue, Jenkintown, Pa.

Digitized by Google

CONTENTS[1]

PAGE

STANDARDS COMMITTEE MEETING..... 2

BUSINESS SESSION OF SOCIETY MEETING..... 29

VICTORY DINNER..... 34

TANKS
Herbert W Alden..... 46

AUTOMOTIVE ORDNANCE APPARATUS
Lieut-Col William G Wall..... 59

PRINCIPLES OF THE WHEELED FARM TRACTOR
Edward R Hewitt..... 83

AUTOMOTIVE APPLICATIONS OF MARINE ENGINES IN THE WAR
George F Crouch..... 112

POSSIBLE EFFECT OF AIRCRAFT ENGINE DEVELOPMENT ON AUTOMOBILE PRACTICE
Henry M Crane..... 137

COMPARISON OF AIRPLANE AND AUTOMOBILE ENGINES
Howard C Marmon..... 146

PROBABLE EFFECT ON AUTOMOBILE DESIGN OF EXPERIENCE WITH WAR AIRPLANES
O E Hunt..... 154

HIGH-SPEED HIGH-EFFICIENCY ENGINES
D McCall White..... 162

STORY OF THE UNITED STATES STANDARD TRUCK
J G Utz..... 185

MORE EFFICIENT UTILIZATION OF FUEL
Charles F Kettering..... 201

UNMINED SUPPLY OF PETROLEUM IN THE UNITED STATES
David White..... 220

STATUS OF REFINERY PRACTICE WITH REGARD TO GASOLINE PRODUCTION
E W Dean..... 229

INTERPRETATION OF THE ENGINE-FUEL SITUATION
Joseph E Pogue..... 237

[1]General Index to subjects will be found at the end of the volume.

Digitized by Google

PAGE

FUEL ECONOMY OF AUTOMOTIVE ENGINES
H C Dickinson 262

MEXICO AS A SOURCE OF PETROLEUM AND ITS PRODUCTS
R De Golyer 286

FIXED RADIAL CYLINDER ENGINES
John W Smith 294

PROBLEMS OF THE NAVAL AIRCRAFT FACTORY DURING THE WAR
Com F C Coburn 304

AIRPLANE AND SEAPLANE ENGINEERING
Com H C Richardson 333

OPERATIONS OF NAVAL AIRCRAFT
Com J H Towers 373

LIBERTY AIRCRAFT ENGINE
J G Vincent 385

MAKING THE AIRPLANE A UTILITY
Grover C Loening 433

EXPERIMENTAL AERONAUTICAL ENGINEERING
Alexander Klemin 447

PNEUMATIC TIRES ON TRUCKS
B B Bachman 459

MOTOR-TRUCK CHASSIS DESIGN
Cornelius T Myers 472

TRACTOR MEETING 490

GAS TRACTOR TESTING
J B Davidson 504

AERONAUTIC MEETING 511

COMMERCIAL FUTURE OF AIRPLANES FROM AN ENGINEER'S STANDPOINT
C H Day 512

CASE FOR THE AIRSHIP
Ladislas d'Orcy 521

AIRCRAFT RADIATORS
Archibald Black 534

NAVAL AIRSHIPS
Com J C Hunsaker 578

ADDRESSES AT THE HOME-COMING SUPPER 590

ENGINE PERFORMANCE
H L Horning 602

MODIFIED DESIGN OF CLASS B TRUCK ENGINE
A F Milbrath 616

Digitized by Google

PAGE

PROGRESSIVE AND RETROGRESSIVE DESIGNING
Otto M Burkhardt..... 623

CORRECT LOCATION OF BRAKE LEVERS
Walter C Baker..... 657

CONDITIONS IN THE AUTOMOTIVE INDUSTRY ABROAD
David Beecroft..... 669

ADAPTING THE FUEL TO THE ENGINE
E W Dean and J P Smootz..... 683

HOT SURFACE OIL ENGINES FOR INDUSTRIAL PURPOSES
A H Goldingham..... 689

PRESENT POSITION OF THE DIESEL ENGINE AS APPLIED TO MARINE SERVICE
Thomas O Lisle..... 701

LUBRICATION AND FUEL TESTS ON BUDA TRACTOR TYPE ENGINE
P J Dasey..... 714

HIGH-COMPRESSION OIL ENGINE
W G Gernandt..... 726

CARBURETER AIR CLEANERS
W G Clark..... 745

RADIATOR COOLING FANS
George W Hoyt..... 758

TRACTOR DRAWBAR IMPLEMENTS AND THEIR HITCHES
F N G Kranich..... 777

VARIABLE-SPEED GOVERNORS
W W Wells..... 784

Digitized by Google

ANNUAL MEETING

OF THE

SOCIETY OF AUTOMOTIVE ENGINEERS

INC.

NEW YORK CITY

FEB. 4, 5 AND 6, 1919

Digitized by Google

MEETING OF THE STANDARDS COMMITTEE

The Standards Committee of the Society held a meeting on Feb. 4 to pass upon the work accomplished since the Semi-Annual Meeting held at Dayton in June, 1918. Chairman B. B. Bachman presided and consideration was given to thirty-one recommendations submitted by the Ball and Roller Bearings, Chain, Electrical Equipment, Engine, Miscellaneous, Springs, and Tire and Rim Divisions.

The reports as finally accepted by the Committee and reported to the meeting of the Society on the following day are given on the following pages, together with the discussion at the meeting of the Standards Committee. [All S. A. E. Handbook page references refer to the Handbook as of February, 1919]

Ball and Roller Bearings Division

(Report as adopted by the Society)

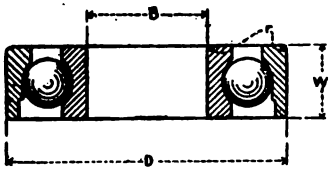
Annular Ball Bearings, Separable (Open) Type

The proposed sizes of separable (open) type bearings which are recommended as S. A. E. Standard are complete with the exception of the tolerances, which are yet to be decided. These bearings are extensively used in magnetos and other small types of machines.

No.	B		D		W of Individual Rings		r Corner Radius	
	Mm.	Inches	Mm.	Inches	Mm.	Inches	Mm.	Inches
5	5	0.19685	16	0.62992	5	0.19685	0.3	0.008
6	6	0.23622	21	0.82677	7	0.27559	0.3	0.012
7	7	0.27559	22	0.86614	7	0.27559	0.3	0.012
8	8	0.31496	24	0.94488	7	0.27559	0.3	0.012
9	9	0.35433	28	1.10236	8	0.31496	0.3	0.012
10	10	0.39370	28	1.10236	8	0.31496	0.3	0.012
11	11	0.43307	32	1.25984	7	0.27559	0.4	0.016
12	12	0.47244	32	1.25984	7	0.27559	0.4	0.016
13	13	0.51181	30	1.18110	7	0.27559	0.3	0.012
14	14	0.55118	35	1.37795	8	0.31496	0.5	0.020
15	15	0.59055	35	1.37795	8	0.31496	0.5	0.020
16	16	0.62992	38	1.49607	10	0.39370	1.0	0.040
17	17	0.66929	44	1.73229	11	0.43307	1.0	0.040
18	18	0.70866	40	1.57481	9	0.35433	1.0	0.040
19	19	0.74803	40	1.57481	9	0.35433	1.0	0.040

NOTE.—For temperature of measurement and definition of eccentricity, see S. A. E. Handbook, vol. I, page 29cc.

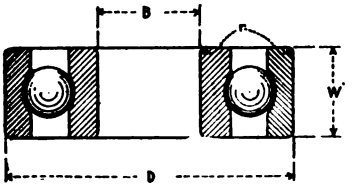
Digitized by Google



SEPARABLE (OPEN) TYPE OF ANNULAR BALL BEARING

Annular Ball Bearings, Extra Small Series

This series, which is recommended as an S. A. E. Standard, is complete with the exception of all tolerances, which are yet to be decided. It is intended for use in airplane sheave pulleys and special apparatus.



EXTRA SMALL SERIES OF ANNULAR BALL BEARING

No.	B		D		W of Individual Ring		r Corner Radius	
	Mm.	Inches	Mm.	Inches	Mm.	Inches	Mm.	Inches
9430	4	0.15748	16	0.62992	5	0 19685	0.5	0.02
9431	5	0.19685	19	0.74803	6	0 23622	0.5	0.02
9432	6	0.23622	19	0.74803	6	0.23622	0.8	0.03
9433	7	0.27559	22	0.86614	7	0.27559	0.8	0.03
9434	8	0.31496	22	0.86614	7	0.27559	0.8	0.03
9435	9	0.35433	26	1.02363	8	0.31496	0.8	0.03

NOTE.—For temperature of measurement and definition of eccentricity, see S. A. E. Handbook, vol. I, page 29cc.

Angular Contact Ball Bearings

The Division recommends that the following paragraph be printed in the Handbook, instead of duplicating the tables already printed for the regular Annular Ball Bearings.

"Ball bearings of the angular contact type are identical in sizes and boundary dimensions with S. A. E. Standard Annular Ball Bearings in the Light, Medium and Heavy Series, as printed on pages 29, 29a and 29b, S. A. E. Handbook, vol. I."

In presenting the report of the Division, F. G. Hughes, chairman, said that the series of separable (open) type

Digitized by Google

bearings had been known to the members in the past as magneto bearings, which found their first use in magnetos and similar small electric apparatus not only in this country but abroad. The list of bearings showed a rather logical progression as to bore sizes, but the progression of the outside diameters was not regular. The only plea that could be put forward for the list as it now stood was that it had met almost universal practice not only here but abroad for the purpose for which these bearings were intended. So many thousands and possibly millions of these bearings are out and constantly being manufactured to these dimensions that it would seem almost impossible to throw them out and standardize a series of bearings not required where this present list apparently meets all requirements.

Chain Division

(Report as adopted by the Society)

Roller Chain Nomenclature

The Chain Division, which has been working jointly with the A. S. M. E. Steel Roller Chain Committee, recommends changing the standard roller chain designation from "Universal No." to "Manufacturer's Standard No." This change will be incorporated in the present S. A. E. Recommended Practice for Roller Chain Dimensions, as given on page 14c, S. A. E. Handbook, vol. I, which practice was adopted in 1918 as a war-time standard.

Manufacturer's Standard No.	Pitch	Chain Width[1]	Roller Diameter
2	½	¼	0.306
2½	⅝	⅜	0.400
3	¾	½	15/32
4	1	⅝	⅝
5	1¼	¾	¾
6	1½	1	⅞
7	1¾	1	
8	2	1¼	1⅛
10	2½	1½	1 9/16

Dimensions are in inches.

[1]Distance between the inside plates.

Digitized by Google

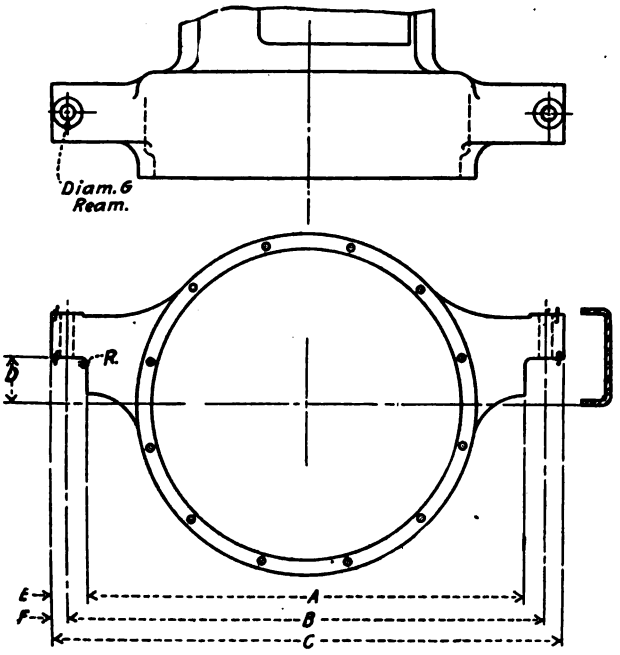
Engine Division

(Report as adopted by the Society)

Engine Support Arms for Trucks Only

The Engine Division recommends as S. A. E. Recommended Practice engine rear support arms in two sizes, the large size for the No. 1 S. A. E. flywheel housing and the small size for the Nos. 2, 3 and 4 S. A. E. flywheel housings. Further standardization to include the front rocker bearing is being considered by the Division, and if it seems desirable to standardize this part of the mounting a recommendation will be made at a later date.

S. A. E. Flywheel Housing	A	B	C	D	E	F	G	R
No. 1.....	23½	26¾	28¾	2	2⅝	1	0.750	7/16
Nos. 2, 3 and 4...	23½	24½	25¾	2½	2 5/16	⅝	0.625	⅜



Engine Rear Support Arms

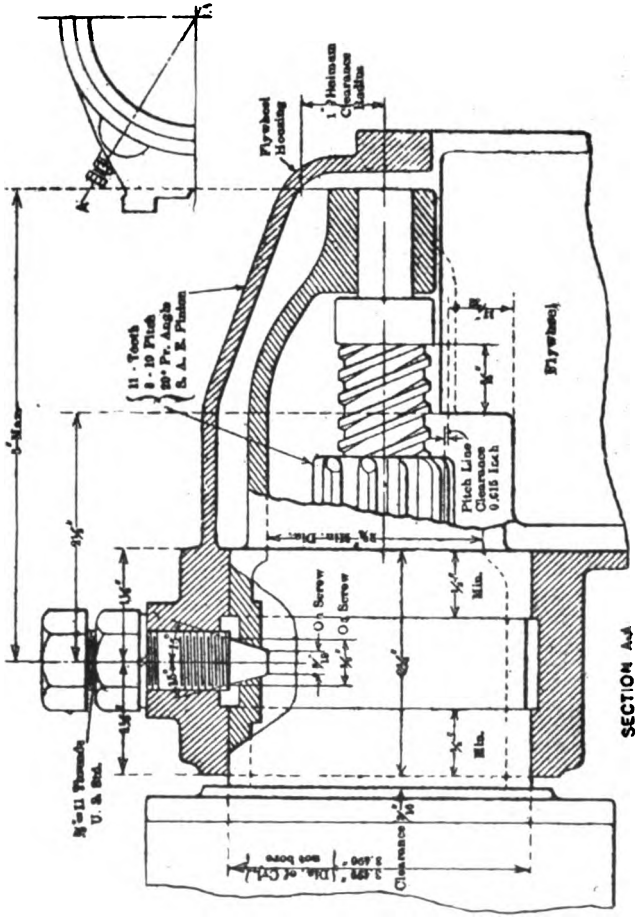
Digitized by Google

Electrical Equipment Division

(Report as adopted by the Society)

Barrel Mounting for Starting-Motors

The barrel or cylindrical type of starting-motor mounting has come into more or less general use, and the Division recommends the accompanying drawing for adop-



Sleeve or Cylinder Type of Starting-Motor Mounting

tion as S. A. E. Recommended Practice. It is the opinion of the Division that this mounting should be used only for outboard mesh installations, as it is not considered a suitable type for inboard constructions. The mounting

Digitized by Google

consists of a cylindrical portion of the gearshift housing sliding into a bored hole in the bell-housing, the length of which is about two-thirds the diameter of the bore. The motor is locked in position by a screw through the bell housing entering a tapered hole in the cylindrical portion of the gearshift housing. This mounting is for use with the standard eleven-tooth pinion assembly.

THE DISCUSSION

R. J. BROEGE: Is the location of the gear on the flywheel given in the same relation from the flange as with the other two pads?

W. A. CHRYST: This, having no flange, wipes that out.

MR. BROEGE: What I was thinking of was that some crankcases might be fitted with the old flange and this type of mounting could be used.

MR. CHRYST: If you compare the types, you see it would not be possible to bolt on an old flange if you use this type of mounting. This type was specified for cases where it is impossible to use the flange and in which there would be no advantage in making allowance for its use.

MR. BROEGE: This is preferable to the other mountings, but where crankcases are fitted with the other flange, you could not apply this starter mounting.

MR. CHRYST: By the use of an adapter I think this could be put in very easily.

Non-Magnetic Magneto Shims

This subject was considered last year, but has been reconsidered because of difference in opinions regarding its specification. The industries have again been circularized and as a result the Division recommends as S. A. E. Standard that when it is desired to use a non-magnetic shim with magnetos mounted on cast-iron pads, the shims shall be ½ in. thick and high-strength bronze bolts used. The thickness of the shim shall be added to the dimension *N* on the drawing, data sheet 36, S. A. E. Handbook, vol. I, when laying out the distance from the face of the mounting pad to the center of the magneto shaft. It is suggested that a grid construction be used for the shims.

Magneto Couplings—Flexible Disk

After carefully considering the data accumulated on this subject, the Division has made the following recom-

Digitized by Google

mendation to cover flexible disk couplings for magneto drives:

Outside diameter of disk, 2¾ in.
Inside diameter of disk, 1 in.
Diameter of bolt circle, 2 in.
Thickness of disk, ¼ in.
Number of ¼-in. bolts equally spaced, 4

This recommendation, together with the driving shaft-end coupling dimensions, printed on pages 36 and 36xa, S. A. E. Handbook, vol. I, completes the S. A. E. Standard for magneto disk couplings.

[Important criticisms of this proposed standard were received from several members of the Society with their letter ballots. These were considered by the Council of the Society and the recommendation was printed in the Handbook with the qualifying note: Not intended for use with impulse-type couplings.]

Miscellaneous Division

(Report as adopted by the Society)

Nuts for Machine Screws

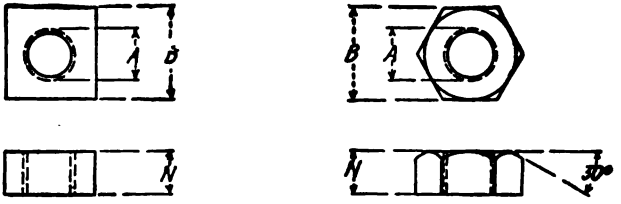
In the past machine screw nuts have varied greatly in proportions. After long consideration the Miscellaneous Division, in cooperation with the A. S. M. E. Committee and the machine screw nut manufacturers, recommends the following machine screw nut sizes and proportions for adoption as S. A. E. Standard.

In presenting the report on this subject, E. H. Ehrman, chairman of the Division, said: "The only comment I have to offer in connection with the specifications is that, in view of the possible time when the number sizes of screws will stop at No. 12, the numbers larger than 12 would be replaced by fractional sizes; ¼ in. for No. 14, 5/16 in. for No. 20, ⅜ in. for No. 24, and ⅞ in. for No. 30. This will in no way affect the outside dimensions of the nut, and it is brought to your attention merely to avoid any misunderstanding or confusion in case any later Division action may eliminate the decimal sizes above No. 12.

THE DISCUSSION

E. H. Ehrman: In the first place, nuts for machine screws are usually punched, have rough exterior, and are not very accurately made; the holes are not counter-sunk

Digitized by Google



NUTS FOR MACHINE SCREWS

SIZE A		Short Diameter (B)	Nominal Thickness (N)
No.	Decimal		
0†	0.060	$\frac{1}{8}$	0.045
1†	0.073	$\frac{5}{32}$	0.055
2	0.086	$\frac{3}{16}$	0.065
3	0.099	$\frac{7}{32}$‡	0.074‡
4	0.112	$\frac{1}{4}$	0.084
5	0.125	$\frac{9}{32}$‡	0.094‡
6	0.138	$\frac{5}{16}$	0.104
*			
8	0.164	$\frac{11}{32}$	$\frac{1}{8}$
*			
10	0.190	$\frac{3}{8}$	$\frac{9}{64}$
12	0.216	$\frac{7}{16}$	$\frac{5}{32}$
14	0.242	$\frac{1}{2}$	$\frac{3}{16}$
*			
18	0.294	$\frac{9}{16}$	$\frac{1}{4}$
20	0.320	$\frac{19}{32}$	$\frac{1}{4}$
*			
24	0.372	$\frac{11}{16}$	$\frac{5}{16}$
*			
30	0.450	$\frac{25}{32}$	$\frac{3}{8}$

*Intermediate sizes Nos. 7, 9, 16, 22, 26 and 28 are special; their dimensions are the same as for Nos. 6, 8, 14, 20, 24 and 24.

†Made from bar stock only.

‡Unless made from bar stock, Nos. 3 and 5 will be made the same dimensions as Nos. 2 and 4 respectively.

Table gives all stock sizes for square and hexagon machine screw nuts of brass, iron and steel.

but only tapped, leaving the partial threads unfinished at each side of the nut. Moreover, this specification has been adopted in toto by all of the machine screw nut manufacturers, and satisfies the requirements originally laid down by the Navy, which are:

> That the tap size of the nut should be easily distinguishable by the outside dimensions, which means that no two tap sizes should have the same outside dimensions
>
> That especially in the larger sizes the dimensions of the nuts should require no new wrench sizes

Digitized by Google

With reference to the aeronautic S. A. E. standards, which were adopted approximately a year ago, I would say that the nuts, according to the standard, are made from the bar; the specification calls for both ends of the tapped hole being counter-sunk, which might remove, through carelessness, more thread than is intended. That is one reason why the thickness of the nut was made approximately 0.01 in. more in the case of the No. 4 nut.

On the other hand, at the meeting of the Aeronautic Division that had the formulation of this specification in hand, it was decided that 3/32 in. should be the thinnest nut, and also the thinnest head; also that the next size above No. 4 should have a thickness that would be proportionate to the size, based on the No. 4 and the nut size above it. This made it necessary to make the thickness of the nut 0.109 in. You will see that the aeronautic nut specification was rather tied up to earlier specifications formulated by the Aeronautic Division.

On the other hand, I see no real need for trying to coordinate the two. Each one serves its purpose. There is going to be no confusion whatever. A machine screw nut is made with such large tolerances and width limits, that it would be unsuitable for aircraft work.

Another feature that enters into the specification for the aircraft series is that of reducing the number of wrench openings to a minimum. Consequently, not alone in the two sizes mentioned is the short diameter made the same, but also in some of the larger sizes, No. 12 and ¼-in.

I do not see any reason why both standards should not stand and be adopted by the Society. Further than this, the Aeronautic Division has deviated from the automobile specification in making the thickness of the nut three-quarters of the diameter, rather than seven-eighths and has also instituted a thin series of nuts. I do not see anything whatever in the two specifications that conflicts on account of the difference in use of the nuts.

It remains to be said, however, that inasmuch as the machine screw nut specification has been adopted by the nut manufacturers, it seems hardly wise to make any changes in it. If it is not acceptable to the Society, it will have to be rejected in toto, as it is hardly subject to amendment.

M. W. HANKS: The fact that the aeronautic standards that the Society adopted have been adopted by both the Army and the Navy gives them considerable strength,

Digitized by Google

I hardly think that either the Army or the Navy will feel like changing those standards. It was found advisable, after a long series of tests made about a year ago, to make the aircraft nuts a different standard than was formerly adopted by the Society, because of the classes of steel being used. That was accepted by both the Army and Navy. All their orders are going through with those particular nuts, and they are averse to making any changes.

CHAIRMAN BACHMAN: It is my understanding that this recommendation of the Miscellaneous Division is not a change from the aeronautic standard. This refers distinctly to nuts for machine screws. The thing Mr. Hanks is talking about is plain nuts for aeronautic practice.

MR. HANKS: Quite true. But I see no reason why the standards should not be the same.

MR. EHRMAN: I would like to add that the difference between the standards for aeronautic bolts, and the automobile standards in which the nuts are thicker, is on account of high-tensile steel used in aeronautic practice. Consequently, for the sake of lightness, the heads are made thinner on the aeronautic bolts. In a test made at the Curtiss plant it was found that a nut having a thickness of three-quarters diameter was equal in strength to a heat-treated nickel-steel bolt. So that there is no need of having it thicker. The aeronautic thin nut is a finished product. A machine screw nut is a very rough product that can be easily distinguished, and probably would not be used in aeronautic practice at all.

MR. HANKS: It so happens that there are only three sizes. If the series is right, why should they not be put out in other sizes? Another point occurs to me. Why is it the Society adopts an S. A. E. Standard here for these particular sizes, while it has not previously adopted S. A. E. sizes above ¼-in.?

CHAIRMAN BACHMAN: I think the answer is that below ¼-in. the S. A. E. Standard is the A. S. M. E. machine screw thread.

MR. EHRMAN: The aeronautic standard stands by itself. The pitches are not in all cases A. S. M. E., and, more than that, the question of ability to get on the market thirty-seven sizes of stock, made the Committee apprehensive; so instead of what they should have done, they have deviated from that to get sizes that they thought would be commercially obtainable on the market.

Digitized by Google

Instead of the machine screw nuts being compromised, the aeronautic standard was compromised. Further than that, you are not adopting an A. S. M. E. specification; this recommendation is from a joint committee composed of A. S. M. E. and S. A. E. members. Each society can adopt the recommendations of the committee without adopting a standard of the other society.

MR. HANKS: May I ask, Mr. Ehrman, if in the work of the National Screw Thread Commission, there is a tendency to confine ultimate U. S. standard pitches to S. A. E. standard pitches above ¼ in., leaving out the A. S. M. E. sizes above ¼ in.?

MR. EHRMAN: The trend is to abolish number sizes above No. 12, so that ordinary machine screw nuts above No. 12 in size would be made in fractional sizes, to obviate duplications of sizes approximating each other.

MR. HANKS: Anticipating that possible decision, we are standardizing in a series of A. S. M. E. ¼ in. If the outside dimensions of the aeronautic and the machine screw nuts corresponded, it would be all right.

MR. EHRMAN: The machine screw nut dimensions recommended by the Division correspond to from 85 to 90 per cent of the machine screw nuts made in the industry today. This specification is merely a formal presentation of the best practice that has obtained for years.

W. S. HOWARD: I would like to know why, when we make up these tables, we cannot have the long dimensions of the nut included, either in decimals or in the nearest fraction.

MR. EHRMAN: I think that there should be tables among the data sheets, giving the long diameters for different sizes of hexagon and square nuts.

MR. HOWARD: Before we can establish the bolt clearance diameter, we must know the long diameters.

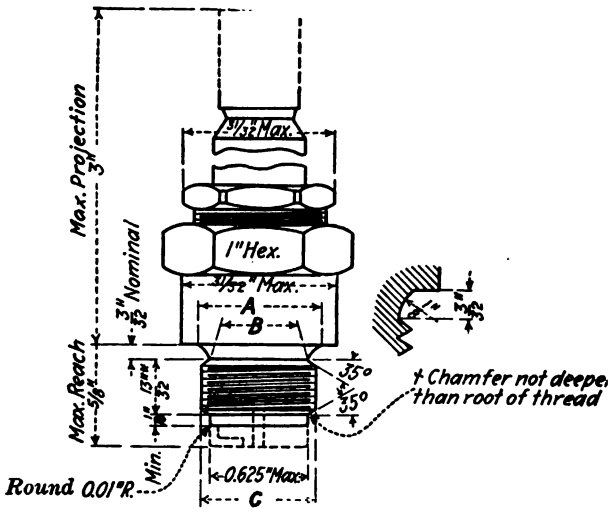
MR. EHRMAN: There is a danger in putting in that specification because users will complain that the long diameters are not as represented. For computation and designs a table among the data sheets that gives that information would be more desirable. The long diameters are in a way necessary in Europe, particularly in France, for the reason that the bolts are made out of round stock, and the heads are square, so that it is a matter of necessity to know what stock is to be used, but in this country where the long diameters cut no figure in manu-

Digitized by Google

facture and the only figure that they cut is in design, we could obtain the information from one table rather than go through all bolt and screw specifications to obtain what we wish. There is no objection whatever to putting it in a separate table with an explanatory note.

Spark-Plug Dimensions—Aeronautic

The extension and revision of aeronautic spark-plug shell dimensions, printed on pages 3a and 3b, S. A. E. Handbook, vol. I, have been considered by the Division,



*7 threads (nearly).
†Not specified by Anglo-American Committee.

AERONAUTIC SPARK-PLUG SHELL

with a view to bringing the present S. A. E. Recommended Practice into harmony with a desired international standard.

In presenting a verbal report on this subject Mr. Ehrman said that this shell follows very closely the recommendations of the British Engineering Standards Association, with the exception of a few changes in the maximum projection, which was reduced from 3½ to 3 in.; the length of the thread, which was changed from 21/64 to 13/32 in., and the note, which was changed from five threads to seven threads nearly. These will in no way bar use of the spark-plug in British engines; in fact the Division is in receipt of a letter from

Digitized by Google

Rolls-Royce, Ltd., in which the statement is made that it prefers a cylinder-wall thickness of 0.6 in. to a wall thickness of 0.5 in. This, together with the fact that 0.6 in. meets the Liberty engine dimensions, as well as those of other American makes of engine, influenced the making of these changes. Also, it was found that the spark-plugs used on a large number of American engines corresponded to the plugs having dimensions as revised.

THE DISCUSSION

C. C. HINKLEY: I would like to ask Mr. Ehrman's opinion on the amount of space he has allowed to bend the wire at the bottom of the plug. He states that the 21/64 in. dimension has been increased. That cuts down the space allowed for the wire.

MR. EHRMAN: The diagram merely shows an optional way of using that space. This is not the best construction or the preferred construction, and our changes were made in strict accordance with the preferred construction; also so as not to interfere with the British specifications. The British will not make use of the petticoat below the thread; they do not like it. In this country we prefer it. The British will mount the electrode as though there were no petticoat there, whereas we would extend the petticoat to the distance shown; and the one electrode will be a pin running across the diameter, and passing through the petticoat. The recommendations fit both the British requirements, and the best we can find with reference to American requirements.

MR. HINKLEY: In aeronautical plug practice is it proper to use wire electrodes extending below the skirt of the plug?

MR. EHRMAN: Our suggestion permits it.

MR. HINKLEY: The idea being that it is permissible in our construction to make that distance greater in the wire if we wish?

MR. EHRMAN: Yes.

H. M. CRANE: The screw thread terminal recommended by the Division is certainly not common.

CHAIRMAN BACHMAN: Is there any objection to having it as an option?

MR. CRANE: I do not know that there is any objection. We do want some type of snap terminal, without a doubt.

MR. EHRMAN: There are no dimensions on the fastening device other than the 8-32 A. S. M. E. thread, so that

Digitized by Google

if the thread is not to be used, the shape of the terminal could be modified as desired; or the matter might be further considered by the Division as to standardizing the terminal for use in this country.

CHAIRMAN BACHMAN: Would it materially affect the proposition, if all reference to the terminal end were left off? That is, would the action you are desiring to take be accomplished if that were left off?

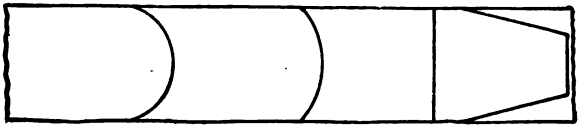
MR. EHRMAN: Yes.

SPRINGS DIVISION

(Report as adopted by the Society)

Leaf Points—Nomenclature

Many of the leaf points shown on page 49b, S. A. E. Handbook, vol. I, are obsolete. The Springs Division



No. 1 Round No. 2 Half Round No. 3 Square No. 4 Blunt Diamond
LEAF POINT NOMENCLATURE

has therefore prepared the accompanying series of leaf points as answering all commercial requirements, and recommends that the nomenclature indicated be adopted as S. A. E. Standard.

Leaf Points

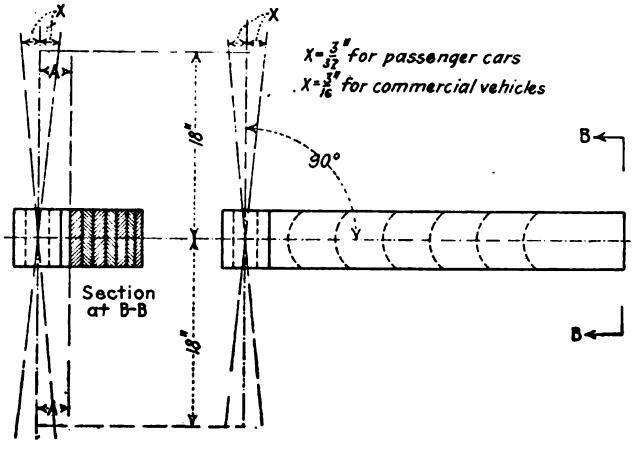
The following leaf points shown above are recommended by the Springs Division for adoption as S. A. E. Recommended Practice:

Leaf Points Nos. 1, 2 and 3 for rolled tapered leaves
Leaf Points Nos. 3 and 4 for full thickness leaves
Rebound clips to be used in all cases

Test for Parallelism

The present 3/16-in. value for angular variation of the eye center line is considered too close for practical commercial vehicle spring tests and the Division recommends that this be specified as ⅜ in. for commercial vehicles as shown in the drawing on page 16, as S. A. E. Recommended Practice.

Digitized by Google



TEST FOR PARALLELISM

Eye Bushings and Bolt Tolerances

The tolerances shown on page 49d, S. A. E. Handbook, vol. 1, are considered too close for practical application. The Springs Division recommends that they be opened up to within commercial limits as follows:

Bushed eyes—plus 0.001, minus 0.003

Bolts for bushed eyes—minus 0.005, minus 0.008

Unbushed eyes—plus 0.001, minus 0.004

Ground bolts for unbushed eyes—minus 0.006, minus 0.009

Unground bolts (hot-rolled) for unbushed eyes—diameter minus 0.006, for maximum so as to use standard reamers

In presenting this report, Walter M. Newkirk, chairman pro tem. of the Division, called attention to the fact that the standard deviation is used with reference to the distance that the eye center line is from a line at right angles to the spring center line at a distance of 18 in. from the spring instead of the total or twice this distance. This tolerance has been doubled in the case of commercial vehicles, principally for the reason that it is practically impossible to attain that degree of accuracy heretofore specified in this class of work.

Supplementing this report on S. A. E. Recommended Practice, Mr. Newkirk said that all of the changes were made with the idea of permitting the use of standard

Digitized by Google

recommended articles which can be bought on the market. The finished sizes of bolts, when they are ground, can, of course, be made just as readily from one range as they can from another.

Wrapped Eyes

The Division recommends that the S. A. E. Recommended Practice on page 49e, S. A. E. Handbook, vol. I, be changed to read: "Where drive is taken through springs on commercial vehicles, the second plate may be loosely wrapped around the eye of the driving end. In all other cases wrapped eyes should not be used."

Width of Spring Ends

It is recommended by the Division that the tolerance for spring widths be changed to 0.005 in. for passenger cars and 0.010 in. for commercial vehicles. The revised S. A. E. Recommended Practice will read, "Spring ends should be finished to a width of 1/16 in. less than the nominal width of the springs, with a plus or minus tolerance of 0.005 in. for passenger cars and 0.010 in. for commercial vehicles, to a point far enough back on the spring to allow free shackle movement or free sliding movement in case of flat-end springs."

Rebound Clips, Spacers and Bolts

It is recommended that the following note be added to page 49u, S. A. E. Handbook, vol. I: "Clearance between the rebound clip bolts (or spacer tubes if used) and spring plates shall not exceed 3/32 in. for passenger cars or 3/16 in. for commercial vehicles."

Spring Widths, Lengths, Eye and Clip Diameters for Commercial Vehicles

It is recommended by the Division that page 49h, S. A. E. Handbook, vol. I, be revised so that in the third line of the first paragraph the expression, "¼ in. larger," will read, "the same," and the following added at the end of the paragraph: ". . . as on the other end, and in agreement with the above table. Considering strength of the main plate, it is believed more desirable to put a heavier load on a bushing than to risk opening up the eye, which might happen if the eye were increased in diameter."

Digitized by Google

Capacity, Tons	Location	Approx. Load per Spring, Lb. (Truck Loaded)	Spring Width, (In).	Min. Length of Spring, In.	Eye Diam. (See Notes)	Spring Clip Diam. (Alloy Steel)	
						Spring Set on Axle	Spring Underslung
¾	Front Rear	To be determined	2 or 2¼ 2 or 2¼	40 50	¾ ⅞	¾ ⅞	¾ ⅞
1	Front Rear		2 or 2¼ 2¼ or 2½	40 50	¾ 1	¾ ⅞	¾ ⅞
1½	Front Rear		2¼ or 2½ 2½ or 3	42 54	¾ 1	¾ ⅞	⅞ 1
2	Front Rear		2¼ or 2½ 3	42 54	¾ 1⅛	¾ ⅞	⅞ 1
3½	Front Rear		2½ or 3 3 or 4	44 56	⅞ 1¼	⅞ 1	1 1⅛
5	Front Rear		3 4 or 5	44 56	⅞ 1¼ or flat end	⅞ 1	1 1⅛
7	Front Rear		3 5	46 58	1 1¼ or flat end	1 1⅛	1⅛ 1¼

The column "Capacity, Tons" is intended only to indicate the general truck capacities on which the corresponding usual spring sizes are used. The above table applies to all types of drives.

Heat-treated alloy steel spring clips shall be used in all cases.

In presenting these two recommendations for acceptance as S. A. E. Recommended Practice, Mr. Newkirk stated that the approximate load per spring had been omitted since the Division felt that it had not sufficient information to state properly what these loads should be. It was also felt that it was desirable to give optional widths of certain of the springs for both classes of vehicles.

Spring Widths and Lengths, Eye and Clip Diameters for Passenger Cars

The data in the tables of spring widths, eye and clip diameters for passenger cars and commercial vehicles have been carefully reviewed and revised by the Division in order to have them accord with current practice. The figures relative to spring lengths are added to the tables, as it is believed they will be of value to car designers.

The third sentence of the notes in the data sheet should be omitted and the following note added, "Heat-treated alloy steel spring clips shall be used in all cases."

Digitized by Google

Shipping Weight of Car, Lb.	Location	Approx. Load per Spring (With Passengers), Lb.	Recommended Spring Length, In.	Spring Width, In.	Eye Diameter (See Notes)	Spring Clip Diameter, In. (Alloy Steel)
Under 2500	Front Rear	To be determined	38 52	1¾ 1¾ or 2	⅝ ⅝	½ $\frac{9}{16}$
2500 to 3000	Front Rear		40 54	1¾ or 2 2	¾ ⅝	$\frac{9}{16}$ $\frac{9}{16}$
3000 to 3600	Front Rear		40 56	2 2 or 2¼	¾ ⅝	¾ ⅝
3600 to 4200	Front Rear		42 58	2 or 2¼ 2¼ or 2½	¾ ⅝	¾ $\frac{9}{16}$

Frame Brackets

It is recommended by the Division that the third paragraph of this subject on page 49e, S. A. E. Handbook, vol. 1, be extended to read, "The distance between the ears of bracket hoods should be 0.010 in. greater than the finished width of the spring eyes, with a minus tolerance of 0.000 in. and a plus tolerance of 0.005 in. for passenger cars. For commercial vehicles the minus tolerance should be 0.000 in. and the plus 0.010 in.," thus making the S. A. E. Recommended Practice cover both classes of vehicles.

Leaf Spring Specifications

In connection with item (f) on page 49i, S. A. E. Handbook, vol. I, the following revision is recommended for the S. A. E. Standard "Method of clamping spring in center."

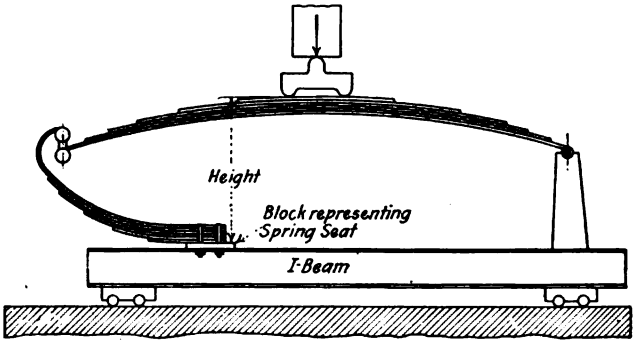
Bolt ..... (S. A. E. Standard)
Nibs ..... (Not recommended)
Band ..... (Not recommended)
Spring seat lengths overall.....
Distance between spring clips.....

It is recommended by the Division that the item (g) on page 49i, S. A. E. Handbook, vol. I, be revised in part to read, "Fill in type of eye as follows, 'In,' 'Out.'"

TYPES OF SPRING EYES

It is also recommended that the illustration be changed to show the words "In" and "Out" as shown in the drawing.

Digitized by Google



THREE-QUARTER ELLIPTIC SPRING COMPRESSION-TEST SUPPORT

The Division recommends that the group of drawings on page 21 be revised to show the position and in some cases the length of the spring seats.

On page 49q, S. A. E. Handbook, vol. I, the drawing is wrong and should be as shown in the accompanying drawing, the rollers being under the I-beam instead of under the end of the spring.

Finishes of Springs

The Division recommended that only three finishes be adopted as S. A. E. Standard, since only that number are really accepted as standard by the trade. These are as follows:

Black—All plates left in the condition in which they left the heat-treating process

Half Bright—Outside surface of the eyes, and the upper exposed portion of the plates to be ground or polished, free from scale. Remaining exposed surfaces to be left black

Bright—To be the same finish as half bright, with the addition that the edges of all plates are to be ground or polished free from scale. Exposed surface on bottom left black

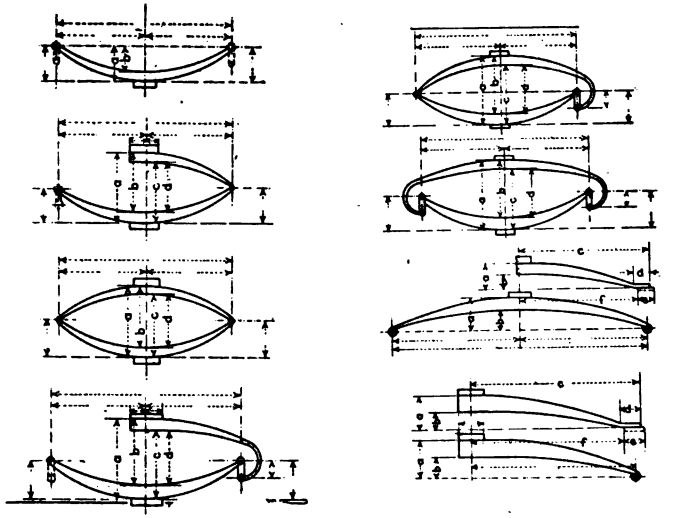
TIRE AND RIM DIVISION

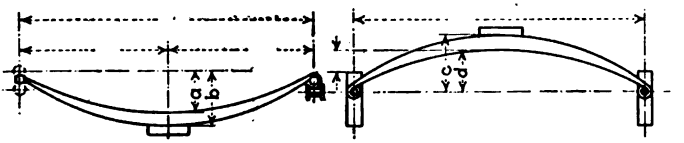
(Report as adopted by the Society)

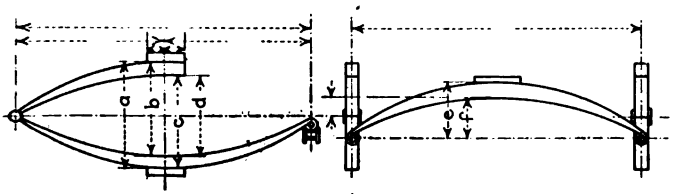
Industrial Truck Tires

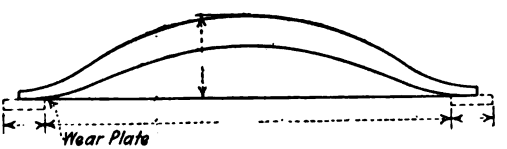
It was found upon investigation that there is little uniformity in present practice for industrial truck tire sizes. After carefully considering the situation the Tire and Rim Division recommends that the following

Digitized by Google









Leaf Spring Specifications

Digitized by Google

industrial truck tire and wheel dimensions be adopted for S. A. E. Standard:

Tire Dimensions		Wheel Dimensions	
Nominal Diameter, In.	Sectional Width, In.	Wheel Diameter, In.	Widths of Felloe, In.
10	3½	6	2¾
10	5	6	4¼
16	3½	12	2¾
16	5	12	4¼
20	3½	16	2¾
20	5	16	4¼
24	3½	20	2¾
28	3½	24	2¾

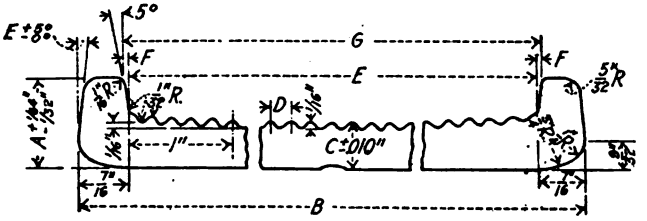
"Wheel diameters shall be 4 in. less than the nominal tire diameters. The height of the finished tire is to be 2 in. for all sizes. The width of the wheel felloe is to be in accordance with the present S. A. E. standard truck tire practice and the rim diameter tolerances will be plus 0.005, minus zero." The acceptance of this recommendation will make all the former or present S. A. E. standards for industrial truck tire sizes null and void.

Base Bands for Solid Tires

The base band dimensions recommended for S. A. E. Standard are shown below. These conform to the recommended series of solid tire sizes and are in accordance with the base bands recommended and adopted by

Base Band Size	A	B	Limits of B	C	Corrugations		E	F	G
					No.	D			
3½	¾	4¼	±1/32	11/32	18	0.191	3 7/16	1/16	3 9/16
4	25/32	4 13/16	±1/32	⅜	20	0.196	3 55/64	9/128	4 1/16
5	27/32	5⅞	±1/32	7/16	26	0.189	4 55/64	9/128	5 1/16
6	27/32	6⅞	±1/32	7/16	32	0.185	5 55/64	9/128	6 1/16
7	27/32	7⅞	±1/32	7/16	36	0.192	6 55/64	9/128	7 1/16
8	⅞	8⅞	±3/64	7/16	40	0.196	7 27/32	3/64	8
10	⅞	10⅞	±3/64	7/16	50	0.196	9 27/32	3/64	10
12	⅞	12⅞	±3/64	7/16	60	0.197	11 27/32	3/64	12
14	⅞	14⅞	±3/64	7/16	70	0.197	13 27/32	3/64	14

Digitized by Google



BASE BANDS FOR SOLID TIRES

the War Service Committee of the Rubber Industry of the U. S. A. The recommended bands relate to corrugated mill sections and it is optional with tire manufacturers to use either mill corrugated or dovetail facings, as the same general dimensions apply to bands with either facing.

THE DISCUSSION

J. E. HALE: I believe we should have a standard which will ultimately be one thing or the other, and that we will make a mistake if we adopt a standard which makes corrugated or dovetail facings optional on base bands. Furthermore, there is a detail in dimension on the base band that I would like to see changed; the curve at the lower corner, on the under side, does not provide the most effective lead for pressing on the tires. Eliminate the ¼-in. radius altogether. I would like to see the recommendation of the Division on base bands changed to read that the S. A. E. Standard base shall be corrugated, and that that particular detail in connection with the dimension of the band should be changed as first specified by me.

C. B. WHITTELSEY: Relative to the first point that Mr. Hale brings out, to get all these bands corrugated and leave out the dovetail, I think that would work a hardship on a number of solid tire manufacturers, and could not be carried through successfully. It would limit the design there, which has been worked successfully since the first base bands were made.

MR. HALE: This base band standard has been the subject of very thorough deliberation by the War Service Committee of the Rubber Industry, and it was definitely understood that the ultimate standard would be a corrugated base. It was admitted that there might be some manufacturers who would want to use a dovetail base until they had worked out some improvements. But bear

Digitized by Google

in mind the big idea of a base standard was to have one standard, so as to simplify production. We shall not accomplish what we should, if we have a dual standard. The understanding in the Rubber Committee was that anybody who wanted to use the dovetail for the time being was to have this privilege, but that the ultimate standard was to be a corrugated standard.

J. G. SWAIN: I was secretary of the Solid Tire Committee of the Rubber Industry that considered this subject, and it was the consensus of opinion of the Committee that the solid tire manufacturers were not in a position at this time to recommend a definite form of corrugation or facing for a base band, and the minutes of the meeting and the records of the various meetings of the Committee will show that they were not ready to adopt a definite standard. The matter was left open as optional, and I am sure that that is the position that the majority of the solid tire manufacturers take on the way this subject should be handled. Furthermore, I think that it is really beyond the functions of this Society to adopt a standard here without it having been recommended by the industry, which is so vitally interested in the subject, and I think that the matter should be left as recommended right here in this report. If at any time the solid tire manufacturers are ready to recommend a definite standard as to the facing of the base band for a solid tire, they will submit that to the proper committee of this Society, with the request that it be adopted.

W. N. DUNCAN: I also was on the War Service Committee and think that Mr. Hale's opinion is incorrect regarding this facing.

W. M. BRITTON: I believe the Society should not take the position of deciding definitely on the particular kind of facing that should be used on the base band. I believe that should be left to the particular user of the band, or the tire manufacturer. I believe, however, that it would be a step in the right direction to standardize the outside contour of the band itself. The recommendation of the Division should stand, permitting either the corrugated or the dovetail facing.

C. B. WILLIAMS: This report, I take it, relates to certain sizes and makes it optional whether the dovetail or the corrugated facing is used. Both of these sections are being used now. I think this discussion is all beside the point.

Digitized by Google

MR. SWAIN: The subject of contour was discussed at some length at the various meetings of the committee. It was the consensus of opinion that inasmuch as the contour shown in the report had been used successfully by one of the larger tire manufacturers and was one of the simplest rollings to secure from the mills, it was quite adequate for the purpose intended, to facilitate the application of the solid tire to the felloe band. I believe that the recommendations of the Committee should stand as they are in the report.

W. C. KEYS: The Committee considered a long chamfer that ran back under the upturned flange of the band, but the point was brought out that this resulted in too little support in the mounting of the band. Therefore the recommendation given in the report of the Division was decided upon.

Base Bands for Industrial Truck Wheels

The sections of tires and base bands as recommended for solid tires for trucks also apply to industrial truck wheels, and the Division recommends that the recommended S. A. E. Standard 3½ and 5 in. pressed-on channel sections shown in the drawing on page 23 be adopted for industrial truck wheels.

Solid Tire Sections

In first working on this subject the intention was to standardize the sections and contours for solid tires but as this would tend to limit the design of solid tires, the Division recommends that the minimum total cross-sectional rubber area of solid tires on standard bands for commercial vehicle wheels shall be as shown in the

Solid Tire Width, In.	Minimum Total Sectional Area of Rubber, Sq. In.
3½	6.75
4	7.75
5	10.75
6	13.75
7	16.75
8	19.75
10	25.75
12	31.75
14	37.75

Digitized by Google

table on page 25, which is in complete accord with the schedule worked out and adopted by the Solid Tire Division, War Service Committee of the Rubber Industry of the U. S. A. These areas include the hard and soft rubber used in solid tires and are recommended for acceptance as an S. A. E. Standard.

Wood Felloe Dimensions—Pneumatic Tire Rims

At the June, 1918, meeting of the Society wood felloe dimensions were adopted for only the 6, 7 and 8-in. rims. To complete this specification for 3½, 4 and 4½-in. rims, the dimensions recommended for S. A. E. Standard are as follows:

Nominal Tire and Rim Size	Width	Depth
30x3½	1½	$1\frac{1}{4}\left\{\begin{matrix}+\frac{1}{16}\\-0\end{matrix}\right.$
32x3½	1½	$1\frac{1}{4}\left\{\begin{matrix}+\frac{1}{16}\\-0\end{matrix}\right.$
33x4	1¾	$1\frac{1}{4}\left\{\begin{matrix}+\frac{1}{16}\\-0\end{matrix}\right.$
34x4½	*2 †2¼	$1\frac{1}{4}\left\{\begin{matrix}+\frac{1}{16}\\-0\end{matrix}\right.$

*Width of felloes for rims with special sections.

†Width of felloes for demountable rims on cold-rolled bands.

These felloe band dimensions conform with those adopted by the Automotive Wood Wheel Manufacturers' Association.

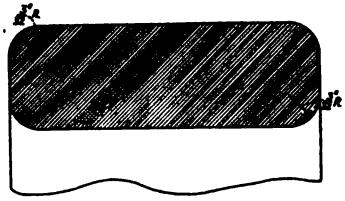
Allowable Tolerances for Felloe Bands

The tolerances given on page 8a, S. A. E. Handbook, vol. I, are used for the inspection of not only steel bands on wood wheels but also for steel wheels. The Division recommends that the wording at the bottom of page 8a, be changed to read, "Band circumference after application to wood wheels and circumferences of steel wheels," to make the S. A. E. Standard applicable to both types of wheel.

Digitized by Google

Edges of Felloe Bands

The present specification as revised at the June meeting in Dayton to 3/16-in. radius on the inside edges and 1/16-in. radius on the outside edges of bands, is a specification to which it is practically impossible to get the mills



EDGES OF FELLOE BANDS

to roll steel. The Division therefore recommends that the edges of felloe bands be changed to 3/32-in. radius for all edges. This proposal is approved by both wheel and tire manufacturers and is presented for acceptance as an S. A. E. Standard.

Pneumatic Tires for Motorcycles

The present S. A. E. motorcycle tire sizes printed on page 8k, S. A. E. Handbook, vol. I, are 2¼, 2½, 2¾, and 3-in. sectional diameters. In order to bring the S. A. E. table up to date and have it complete, the Division recommends the following for adoption as S. A. E. Standard. As the tendency in motorcycle design is toward heavier types of machines, the recommended tire sizes are considered ample, and conform to the sizes recommended and adopted by the War Service Committee of the Rubber Industry of the U. S. A.

Nominal Tire Size		Oversize Tire		Tire Seat, Diameter of Rim		Type of Rim
In.	Mm.	In.	Mm.	In.	Mm.	
26x2¼	60/535	None	None	21	535	BB
28x3	75/560	29x3½	90/560	22	560	CC

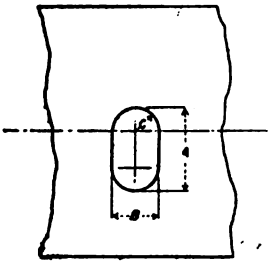
[Negative votes and important criticisms of this proposed Standard were received from several members of the Society with their standards letter-ballots. These were considered by the Council of the Society and the

Digitized by Google

specification was withheld from publication in the Handbook to afford the Tire and Rim and the Motorcycle Divisions time to make further investigation.]

Valve-Hole Size—Automobile Rims

A ⅝-in. diameter valve-hole has already been standardized for the 3½, 4 and 4½-in. rims. The Division



Rim Size (Inches)	Valve-Hole (Inches)		
	A	B	C
6	1⅛	⅝	5/16
7	1⅛	⅝	5/16

VALVE-HOLE SIZE FOR GIANT DEMOUNTABLE AND STRAIGHT-SIDE TRUCK RIMS

now recommends valve-hole sizes for the 6 and 7-in. rims as shown on the accompanying drawing, to be included with the present Standards.

Digitized by Google

BUSINESS SESSION OF SOCIETY MEETING

The business session was called to order on Wednesday morning, Feb. 5, by President C. F. Kettering.

H. L. Pope, E. W. Weaver and Joseph Schaeffers were appointed to act as tellers to count the ballots cast for officers of the Society.

A report was then presented by the Standards Committee on the matters approved at the committee meeting held the previous day. This covered reports on standards and recommended practices prepared by the Ball and Roller Bearings, Chain, Electrical Equipment, Engine, Miscellaneous, Springs, and Tire and Rim Divisions which were approved for submission by letter ballot to the membership at large.

General Manager Clarkson made a brief report on the membership of the Society, showing an increase of the number of active members from 3218 on Jan. 1, 1918, to 3866 on Jan. 1, 1919.

The professional papers presented at the Wednesday morning session included one by Lieut.-Col. Herbert W. Alden, who had been in practical charge of Army tank engineering matters since the Government entered the war, outlining briefly the history of the tank and describing some of the engineering features of the types developed in this country. Other papers presented at this session were by Edward R. Hewitt dealing with The Principles of Design of the Wheeled Farm Tractor, and by George M. Crouch relating to The Performance of Marine Automotive Equipment in the War, with particular reference to the submarine chasers.

At the opening of the Wednesday afternoon session President-elect Manly spoke a few words of appreciation of the honor which the Society had conferred on him. The year 1918, he stated, was undoubtedly the greatest year in the history of the Society, and he pointed out that the biggest asset the Society has is the wonderful spirit of cooperation that exists among its members. He emphasized the fact that in spite of the excellent work accomplished in 1918, even better things could be expected during the present year if the members would cooperate as freely as they had in the past.

Digitized by Google

CONDENSED BALANCE SHEET AS OF SEPT. 30, 1919

Assets		*Liabilities*	
Cash	$22,727.66	Accounts Payable	$9,136.97
Accounts Receivable	21,266.17	Reserve	117,243.75
Investments (Book Values)	70,022.50		
Accrued Interest on Investments	1,591.03		
Inventories	1,474.95		
Total Current Assets	$117,082.31		
Furniture and Fixtures	7,569.83		
Sundry Advances	1,728.58		
	$126,380.72		$126,380.72

Digitized by Google

CONDENSED STATEMENT OF INCOME AND EXPENSE FOR THE FISCAL YEAR ENDED SEPT. 30, 1919

Income from Publications, Advertising and Miscellaneous Sales	$195,361.11
Deduct Cost of Sales	46,334.87
	$149,026.24
Other Miscellaneous Income	19,669.96
	$168,696.20
Expenses	113,282.05
	$55,414.15
Other Charges	6,281.88
NET INCOME	$49,132.27

We hereby certify that, in our opinion, the balance sheet shown above states the true financial condition of the Society of Automotive Engineers as at Sept. 30, 1919, and that the relative statement of income and expense states the true net income for the year ended that date.

Respectfully submitted,
R. G. RANKIN & CO.,
D. EARL FLEMING.

Digitized by Google

A symposium on the probable effect of aeronautic experience on automobile practice was the first subject to be discussed at this session. This consisted of three papers prepared by Henry M. Crane, Howard Marmon and O. E. Hunt. High-Speed High-Efficiency Engines were discussed by D. McCall White; The Story of the United States Standard Truck was told by J. G. Utz, and this paper was supplemented by some remarks by Lieut.-Col. Edward Orton, Jr., on the work and policy of the Motor Transport Corps.

At the Fuel Session on Thursday morning, which was arranged at the request of Dr. Joseph E. Pogue of the Bureau of Oil Conservation, U. S. Fuel Administration, several papers dealing with the subject of Conservation of Fuel were presented. These covered all phases of the problem from the sources of supply and methods of refining to the best way to improve the utilization of fuel by internal-combustion engines.

Aeronautic subjects were considered at the final professional session, which was held on Thursday afternoon. A feature of this session was the presentation of four papers prepared by engineers of the Navy Department who had immediate charge of portions of the naval aircraft program. In addition to these a paper on The Liberty Aircraft Engine was presented by Jesse G. Vincent. Other papers dealing with the use of aircraft over land and water were given, including one on Making the Airplane a Utility, by Grover C. Loening, which dealt with the commercial possibilities of the use of high-speed planes. The factors involved in the design of aircraft were discussed in a paper by Alexander Klemin entitled Experimental Aeronautical Engineering. The concluding paper of the session was on Forest Products for Aircraft Use, by Clyde H. Teesdale of the Forest Products Laboratory. This dealt with the research and development work of the laboratory in connection with the finding of suitable material for American aircraft manufacturers.

Treasurer's Report

Treasurer C. B. Whittelsey submitted a financial report for the fiscal year ended Sept. 30, 1918, which showed assets amounting to $79,008.92, approximately $14,000 of which was cash and $48,000 invested funds, the remainder of the assets being composed of accounts receivable and inventories. These assets exceeded those

Digitized by Google

of the previous fiscal year by $19,334.48, cash and investment being increased by $13,152.81, and inventory and accounts receivable by $6,181.67. The profit and loss account for the last fiscal year showed income amounting to $155,627.69. The operative cost was $140,621.26, leaving a net profit of $15,006.43 for the year.

Social Features

The social side of the meeting was not overlooked. A reception to the retiring and incoming officers of the Society was held on Wednesday evening at the Hotel Astor. A short illustrated address by Col. W. A. Bishop of the Canadian Air Service preceded the reception, which was followed by dancing.

The following night the Victory Dinner was held at the Hotel Astor, at which over 1200 members and guests were present. The Hon. Job. E. Hedges, who was introduced by President Kettering, was toastmaster, and speeches were made by Alfred Reeves, general manager, National Automobile Chamber of Commerce; Charles M. Manly, President-elect of the Society; John N. Willys and George H. Houston.

After the dinner the members and their guests went to the Midnight Whirl at the Century Grove.

Digitized by Google

THE VICTORY DINNER

ADDRESS OF HON JOB E HEDGES

I assume that an automotive engineer is a sort of self-starter, getting everything out of the way as soon as he gets under motion. It follows, therefore, that we know exactly what the Germans think of us Americans. They did not wait to get into contact with us. It is proper that a part of our festivities should be given to celebrating the victory to which we all contributed so markedly. While some of you men were engineering, digging trenches and constructing fortifications, there were some of us at home who had to beg money to support those abroad and to construct an attitude of mind on the part of the public which would resist all the attacks of insidious propaganda, with its attendant weakening of morale. There were also men in doubt as to where they really belonged. They were abundantly informed, however, where their proper place of location was. Some were conscripted and, refusing to fight, were committed to jail. I regret to say that many of these, however, have been discharged with full pay and restoration before the soldiers who did the fighting were given opportunity to resume their peaceful walks abandoned for the war. There are some who were vociferous in their talk before the war, whispered during it, and finally ceased from vocalizing only for reasons of physical safety. In the last mentioned phase of their conduct they indicated real wisdom. They knew better than to belong to the automotive class.

It can be truthfully said that we helped win this victory. It cannot be said, and should not be, that we were the only element in winning the great conflict. I have always envied an engineer because he is taught to rely and necessarily relies on himself. An automotive engineer is entitled to a peculiar meed of praise. Once upon a time I tried to conduct an automotive campaign. Candor compels me to say it was not a success. Possibly one reason was that at that time tanks had not been constructed.

When an engineer strays from his accustomed environment, wanders into the realm of psychology and talks about vision, I frankly admit a degree of confusion. Speaking as an engineer, I view the difference between

Digitized by Google

the German idea of efficiency and ours to be that the German Government reduces men's minds and hands to a common plane of efficiency, leaving the only freedom that of receiving and taking orders. We appeal directly to a man's soul to arouse his vision, so that he takes his own orders from his own intelligence, and our combined action, therefore, represents efficiency, mental, moral and physical, merged into a composite of activity which becomes irresistible. This, among others, is the reason why the Germans were so necessarily and decisively defeated.

With all the temporarily dreadful results, it will ultimately be a good thing for America that the Kaiser has lived, and a good thing for the world when the Kaiser is finally committed to the place that Col. Whittelsey so aptly designated as a proper resting place for the Hun soldier. The Kaiser has thoroughly taught the world what to avoid as a condition of wholesome living, and that his theories furnish no foundation for a structure for modern civilization. He has also demonstrated that a man is at his best when forced to admit that there is something bigger than he is.

Thus it is that the engineer is the best one who admits that the profession of engineering is larger than himself. Engineering becomes a profession when the picture painted and hung represents on the canvas what can best be done for the human race by the individuals who are leaders in thought and action. It is as impossible for a person to live without exercising influence as it is unrighteous that he should attempt so to do. As a matter of logic, entirely apart from morals, no one can intelligently segregate himself to the plane of mere enjoyment and disregard duty as predicated on service. Nor, on the other hand, is our duty confined to our immediate environment. People smile in their own language. The international language is that of ideas, which indicates that human suffering wherever found speaks to every other normal human being in a language easily appreciable and easily responded to in sympathy and assistance. Thus it is that in whatever language we speak, we can readily communicate our ideas to those who are suffering in the cause of righteousness. This is as far as the doctrine of nationalism can well be carried.

When the Kaiser, referred to merely as a type, started out with the assumption that human intelligence, emo-

Digitized by Google

tions and men's souls could be kept within the confines of his dictum, he insulted Almighty God, as well as man's intelligence, and started inevitably on the road to destruction. The man who has not felt through the war a keen thrill, who has not believed and understood that there is a bigger thing in government than his mere relationship to it in receiving benefit, has not learned the lesson of the war. If we stand for anything as Americans, we stand for those wholesome, decent things which we will share with the people of the earth and which we will not endeavor to enjoy in the selfish seclusion of isolation. By this I mean that the United States must always be alert and ready to contend for the maintenance throughout the world of those principles on which we base our own civilization, when those principles are attacked and their practice threatened.

The crucial test of the American people is yet to come. It lies in the problems of sustained endeavor, in the prosaic application of fundamental principles in the approaching years, unaccentuated by the thrill of war or the exultation induced by visible and audible attack from without. Probably no man in this room will live long enough to see American thought as evidenced in its Constitution and traditions restored to primal place. The passion for change, the tendency to novelty, and the political competition for publicity incident to startling advocacy, keep the public mind disturbed and aroused. There is a constant wrenching and straining for something that is new in law without reflecting that in the vast majority of instances there is already enough law properly applied to meet changing conditions and that many of the problems presented have no place in the realm of law, but are social propositions where we seek to shun individual responsibility by shifting the whole question upon the shoulders of officialdom. The standards and ideals of the fathers need study only to insure the revival of an inspired Americanism. As long as there are people sufficiently unintelligent among our members to be deceived, there will always be intelligent minds without moral principles to take advantage of that ignorance for self-exploitation. The responsibility of information, of knowledge, of acquirement, of education, of social and moral wealth, demands peculiar responsibilities toward those less favored. The Republic has a right to expect and to demand from the well capacitated that they shall never institute civic discussion from false

Digitized by Google

premises, and that in talking to those who have a right to look up to them, they shall never deceive. For instance, we did not go into this war to preserve democracy or establish it. We went into this war because our international rights had been attacked and to further condone that attack and violation without rebuking it by armed conflict was to admit that we were without a potential sovereignty. The discussion of preserving democracy for the world or the world for democracy was a proposition that arose afterward, as the vision of the war, unappreciated in its beginning, gradually unfolded to our people. The sustained endeavor of being in the war required for the average mind, not logically but practically, a broader basis than the violation of an international right. Now that the enemy has been defeated, democracy, as popularly known, has been unsuccessfully attacked. Whether it will be affirmatively a successful doctrine and practice and reach to the farthest confines of the world, depends not upon the force of arms, but largely through precept and example. In other words, the possibility and strength of self-government, we can say, without undue pride, is best exemplified in our own form of government. Should we be unsuccessful in maintaining our own standards and meeting under our form of government new and developing propositions, and demonstrate as a result that we are unsuccessful, it will destroy hope throughout Christendom. Therefore, as a matter of substance, with the war over, we are fighting the battle of democracy at home for our own selfish purpose, and in doing that through our example will establish it more firmly throughout the world.

Treason to our Government can come from treasonable utterance as well as treasonable conduct. One who listens without rebuke to treasonable utterance in substance adopts it and is therefore in fact against the government to which he theoretically bears allegiance. He who compromises with the Bolshevik, either materially or mentally, permits that doctrine to progress and substitutes fear for stability in life. Of all bodies of men whose profession requires them to act according to strict scientific lines, to think by rule and formulas and thus work up to their aspirations, with the broadening effect of vision and art combined, that class of men is represented by those whom I am addressing tonight. Therefore, I make an especial appeal to you gentlemen, that you shall contribute your part, as no doubt you will, through the

Digitized by Google

vast scope of your activities to help make it worth while for a man to be able to say "I am an American citizen."

Great as are the heroes of the air, great as are the men who have come back to us from service on or under the ocean, on land or sea, adorned with honors, welcomed with garlands, and with minds alert to the sacrifice that has been made, there still remains the hero at home who has had equal longing to go over there or contribute his life, and whose heroism is shown by the quiet unproclaimed martyrdom with which he has lawfully met duties and at the same time helped contribute to those who did the actual fighting. Heroism hereafter will be marked in the enervating times of peace by the monotonous life of daily duty, where the sacrifice is that of ambition, of wealth, of means, of health, of time, in pursuing silently the dictates of patriotism so genuine that it has neither to be advertised nor bragged of. So sincerely do I feel for men of that class that I am the enemy of anyone who seeks to remain in this country and is unwilling to live according to the letter and spirit of our laws and follow thereby the dictates of our courts and our procedure. To permit such persons to remain here is to pollute our own citizenship. We read in the public press of the contentions of labor, of capital, of organization, the struggle for efficiency, the right to live and let live, the strife as to who shall say how another as well as himself may pursue his daily walk. These things will never be finally solved by argument, statute or uniformed authority until an attitude of mind is established which recognizes that the real test for the right to prefer personal advantage is made subordinate to a duty to government itself.

A peculiar situation has arisen from the war. Among the Allies, naming them just for illustration, we Americans have always had our enthusiasm aroused by mention of the French. It is an anomaly of history that the French monarchy made democracy possible in this country. It is a further anomaly that it was our democracy that helped establish a representative form of government upon the foundations of that very monarchy. Since then we have enlisted our Army and Navy and sent them abroad to help preserve, with our own rights, that same French democracy attacked by a monarchy which grew out of original conditions that in early years furnished precedents for democracy itself.

Sentiment is a bigger, grander thing than law. Each,

Digitized by Google

however, requires the other. The passion for power is instinctive. The continuation of power unduly centered means tyranny. The passion for liberty is a protest against that tyranny. At this point sentiment assumes its sway and by its protest against tyranny furnishes the opposition to overthrow that very tyranny, and the measure of service is marked by the intellect which determines the proportion of effort we are willing to make to sustain the sentiment which we feel.

I can understand the remark that, theoretically, the engineers regretted that the war could not have continued further until the preparations scientifically made for overcoming our enemy could have been put fully into practice. That thought is consistent because, while no one would like to have lost an added life, it would have been satisfying to demonstrate that a democracy could have furnished in its fight for freedom means of contest more effective than could our natural opponent, a concentrated form of government typified by a monarch. However, had those plans been fulfilled there would not have been enough Germans left to reorganize and pay the indemnities. A repenting Hun working to pay the price of his bad judgment and brutality is better than a dead German unregenerate.

ADDRESS OF JOHN N WILLYS

I believe that the time has come to change our theory of labor; the old idea that the capitalist's and the manufacturer's sole aim is to get everything he can out of his labor and give him little for it, is wrong. I think that when Mr. Ford put the $5 per day program in operation he made the biggest hit of his life. The next day after Mr. Ford promulgated his $5 per day plan, my general superintendent came to me and said, "Mr. Willys, what are we going to do? All our men are going to leave us and I do not know what we shall do." I said, "Well, Harry, they cannot all leave us, because Ford cannot take all of them." The superintendent asked if we could put this same plan in operation, and I said we could not. That was the way I felt about it at that time. If I had to do it over, I would not have been 24 hr. in following Mr. Ford's plan. He proved that it was a successful plan from the standpoint of the manufacturer. The man who made radiators made twice as many, be-

Digitized by Google

cause he drove the men. He found the very best labor in the industry would come to him for employment.

I believe in the plan which we are about to adopt of dividing the profit above just compensation for capital. Of course, the lawyer will see that is definitely understood that if we divide the profit we shall get the cooperation of our labor. We are not going to have to drive the labor as Ford did, but are going to get each employe to drive every other employe in our institution to do his duty, to give us a fair day's work. In one of the institutions in which I am interested, we started a piecework plan. One operator on a machine, who had been producing a certain number of parts at day labor and a good day's labor, when this piecework plan was put in operation, gave us the very next day three times as many parts as he did under the old scheme. That shows that labor was not cooperating. While we hear talk about what capital must do, I can say tonight that labor must do its share as well as capital.

I believe that there are a great many ways in which the work will be improved. One will be departmental efficiency. When one department struggles against another for position, we shall, I believe, get great efficiency. I am satisfied that the plan can be worked out. I did not hesitate to put it into operation the first of the year. I think that the way to work it out is not to try to settle details before we start, but to set a date for the plan to go into effect, working out the details later.

ADDRESS OF PRESIDENT-ELECT MANLY

The thing that impresses me more than anything else in connection with the whole war work is the value of cooperation, and foremost the vast amount of cooperation of the engineers. It is well known that most business men have felt that engineers could not cooperate. This war, if it has done nothing else, has proved to the business men of the country that engineers can cooperate.

The work that lies before us now is much more important than what has gone before. The need of cooperation in solving the great problems confronting us, to which our vision has been led by the work during the war, is imperative. The importance, which has been emphasized by Mr. Kettering, of keeping the front door

Digitized by Google

open so as not to shut out many times more than we have in our shop individually has been exemplified by the history of this Society more I think than by that of any other Society of this or any other country. Starting with the automobile trade, and taking the work of the automobile engineer, who was the typical kind of engineer in the Society originally, there is certainly no other body of men in the country devoted to work which involves design and construction requiring vision, in which there is that spirit of wanting to bring everything in through the front door and being careful to avoid locking anything out. A great many people have said that the great conflict we have had was an engineer's war. The question has frequently been asked, "What is an engineer?" It seems to me that the war has helped to answer that to a very large extent. There has never been a business in which the fact was demonstrated so clearly that there is no line of work in which all men who really know how to do things, cannot cooperate to produce the big result. This war has certainly brought to the fore men of every walk of life, of every profession, of every line of thought, and welded them as one. The various thoughts merged into one big, main idea of winning the war, concentrating all attention on that. Now, if we can all concentrate on the big thing that lies before us, which is not merely the building up of trade, but the building up of a strong feeling that this is our country, that we have commenced to take a great deal more interest in it than ever before, and we give to the large questions that lie before the country even a small fraction of the attention we have given to the work of the war, the benefits that will accrue to the country will be very great.

I hope that our work of the coming year will demonstrate that the letters S. A. E. stand not only for Society of Automotive Engineers but for Society of American Engineers.

ADDRESS OF ALFRED REEVES

On behalf of the manufacturers, who are deeply interested in your work and your welfare, I am glad to greet the members of the Society of Automotive Engineers, who are making history in this country. I am particularly glad to greet those engineers who spent the past year with us in Washington, where they did such

Digitized by Google

great work for the war. The war has been a great binder for the men in the automobile industry. It brought even greater cooperation than ever before, which I know will continue and broaden.

Thanks to the efforts of you men in cooperation with the automobile manufacturers, there is now a real appreciation, not alone at Washington, but throughout the country, of the merit of the automobile. Congressmen admit that the passenger car, as well as the truck, has utility value. They declare the proposed new taxes on the industry are made necessary by the war. However, they no longer put automobiles in the class with luxuries. While we must agree that the taxes are unfair and discriminatory, if they are needed to pay our war debt, the automobile manufacturers and dealers are not going to lack in patriotism.

It behooves the automobilists to organize even more highly than they are now organized, to teach our law makers and the public why the time has passed when an automobile owner should be singled out for special taxes not placed on other users of the roads.

We still have some great problems in our country, as well as in our industry, but this is a great nation and I have no fear of the final outcome. I have a profound respect for American good sense and balance. What we want in this country is thinkers, not tinkers; optimists, not pessimists; doers, not doubters; constructionists, not obstructionists. What we need is men with red blood who are willing to speak for the right. We want a square deal for capital and for labor, and a square deal by capital and by labor. This automobile industry, gentlemen, is leading the way to the cure for much of the unrest of which we hear. It has always been a great cooperative industry and taken care of its workers.

My faith in the men who are in this room is such that I have a vision of what the future is going to bring. I see wonderful tractors helping to raise food for the nations of the world, with gas engines doing the heavy work on farms in this great gasoline age. I see airplanes, safe, easy to handle and capable of landing in small spaces. I see a great network of good roads throughout the country as an answer to the only present limiting factor to increased sales of motor cars and trucks.

I see automobiles much lighter, more carefully made, and with engines and carbureters capable of handling the lowest grades of fuel, and supplying greater mileage per

Digitized by Google

gallon of fuel than at present. I see cars with concealed spare tires and concealed folding tops. I see cars with adjustable seats, better spring suspension and scores of other improvements which the public demands and is ready to pay for. And, above all, I see the people of the countries of all the world, with their products, being transported quickly and cheaply in wonderfully efficient motor vehicles designed by the real genius of today, the American automotive engineer.

ADDRESS OF GEORGE H HOUSTON

The science of aeronautics has developed the airplane and the balloon, an aeronautic industry, and great flyers. It has developed throughout the world a group of great engineers. It has given those men who led us in Washington in the development of the whole aeronautical program an opportunity to see what a real man's job could be and how it could be handled.

Our great thought lies with the future. A year ago, at the S. A. E. dinner, we listened to an able presentation of the plans for aeronautical development in this country from a military point of view, and those of us who were engrossed to the absolute limit of our mental and physical capacities in executing that program were much encouraged by what we heard. We saw then the vision of a great air fleet, and as a member of the citizenry of this country who has been working for the past year in this industry, I want to say I am proud to have spent it with those men and under that plan. I have seen it work out from nothing to one of the great movements of America in the war. The war is over now however, and we see a great science, a great industry developed, and a great art which should be an addition to civilization for all time to come. For the moment standing still, marking time, we are all trying to readjust ourselves to the peace-time conditions. We are trying to get the perspective that we must have before we can go on. If I can give you gentlemen the least indication of what our future in this industry can be, I shall feel that my efforts have been thoroughly repaid.

It has seemed to me that in looking ahead the first thing we must do is to formulate more perfectly our theories of aeronautics, our theories of human flight, into an exact science, and crystallize it into tangible,

Digitized by Google

definite data upon which to work. This science today is out of its swaddling clothes, but it is still very immature; those of us who have been working with it for a period realize this much more than the average man. As this science becomes crystallized, our engineers must continue to apply it. We cannot develop aircraft like manufacturers want to build automobiles, because we are some fifteen years behind the automobile. We have got to remain flexible in our ideas; we must respond quickly to the new thought, the new conception, the dream of the inventor. We must keep our designs up to date.

Flight is in the air, over the land, over peoples' houses, and over everything which in the mind of the law is sacred. We have got to develop an entirely new theory of Governmental control. We do not yet know what the law of the air should be; we do not know yet what it can be; we have, as it were, to develop a theory of the fourth dimension before we can establish this legislation. And yet, gentlemen, aircraft can never come into common use in any country until there is a body of laws that will enable us to govern it and to protect ourselves from the reckless and criminal without discouraging or interfering with legitimate flight.

We must, then, begin at once, with the end of our war work, and put the entire aircraft industry through a period of disorganization, and then have a reorganization. When the armistice was signed the war ended. At that time the aircraft industry as a whole was one of the greatest transportation industries of the world, ranking equally with any, except possibly that of steamships. It must immediately reduce itself to only a fractional portion; it must do that without loss of morale, initiative, or any of the resources or personnel or capital that it needs. We can thank God that in the S. A. E. we have a great automotive industry into which this excess of plant facility organization and capital can flow.

If we go about this disorganization courageously and carefully, without hysteria but without any illusions of what the present means, then as the future develops we can again reconstruct. It is of the most vital importance that at this time we carry out this disorganization properly, so that as the period of reconstruction begins we can have a record saying, "Careful management of the liquidation of the investment without undue loss and of the transfer of personnel without injury to that personnel." If we do that, when the reconstruction period commences

Digitized by Google

we can bring back into this industry the facilities and men and capital that we need.

Finally, we must face the application of the airplane to our daily life. This is one of the most fascinating problems ahead of us. We talk with ease about the use of the airplane and the balloon for military purposes; we have talked with the Post Office authorities on the problem of carrying mail; we have discussed with South America the problems of flight, for both mail and passenger purposes. But we are just scratching the surface of the possible application of this wonderful thing that is coming into our lives. What we do with it, as compared with England, France, Italy and Germany, is going to depend upon us. If we as American citizens expect to stand shoulder to shoulder with these people abroad, who have learned even better than we what cooperation means, we have got to do it through such an organization as this.

In redeveloping the whole aeronautical science for peace-time purposes, the whole aeronautical industry for the future, we must depend first of all upon the engineer. If you perform your task properly, if you develop this science, if you apply it in a practical way in the design of your product, if you teach people how your products can be used in everyday life without destruction of life and property, a decade from now we will have in process of development one of the greatest, if not the greatest, transportation industry of our country. In this development the Society of Automotive Engineers must lead.

Digitized by Google

ANNUAL MEETING PAPERS

TANKS

By Herbert W Alden[1]

THE track-laying type of vehicle is, of course, old. The emergency which brought the modern "tank" into existence was the menace of the machine-gun. The tank is simply a device that can approach closely and destroy the gun or its crew. It is fundamentally a man killer, and its strongest points are speed and mobility. It is now an indispensable arm of the military service.

The writer gives a rapid résumé of the fantastic period in design, the early work done on heavy armored cars and the reasons for concentrating on the track-laying type of vehicle. The American type of track was adopted as a foundation and from this and around it France, England and the United States have developed the tanks known through successful use in the war. The British are to be credited with producing the first practical fighting machine of this type. France has two types of machine, one mechanically driven and the other with electric drive, both small. The American Army used both the large and the small machines; the French Renault, selected for light, speedy work, and a modified design of the huge British tank, produced by British and American ordnance engineers working jointly in London during the winter of 1917-1918.

The development of the tank has been almost a romance. The future presents great possibilities for it. Three sizes appear to be needed and they must be fast, easily maneuverable and have a large radius of action.

The purpose of this paper is not a technical consideration of the subject of tanks. The subject is too young and in too rapid a state of flux to warrant such treatment. From time to time, since the signing of the armistice, much technical data have been published, and more will be. Duplication of these here would be a waste of time. Therefore, this paper will be devoted to those phases of the subject which might not otherwise be published.

Like many another trite saying, the old adage that

---

[1]Formerly Lieutenant-Colonel, U. S. A., and assistant to Chief of Ordnance, in charge of tank engineering work. Vice-president, Timken-Detroit Axle Co., Detroit, Mich.

Digitized by Google

"there is nothing new under the sun" is only partly true. When some old idea or device is modified and developed to a point where distinctly new results are accomplished, then that thing is, by right, entitled to be called new. The recent war is responsible for many such new forms of old ideas, and not the least by any means among these things is the tank, which has played so important a part in winning the war.

Reasons for Development of the Tank

The origin of the name has been the cause of many fancy stories. The reason for choosing this name, however, was simply as a blind to conceal the real purpose. There is always a cause for every result, and there was a very serious cause for the coming of the tank. It did not "just happen." Nothing ever does, for that matter. The very urgent need which brought the tank into existence was the menace of the machine-gun. The tank problem cannot be correctly understood nor solved if this fact is lost sight of. This is the first war in which the machine-gun was used in large numbers. It was known before, and used to some extent, but its use in a wholesale manner never before occurred. This use in large numbers very nearly revolutionized warfare. Enough machine-guns, properly placed, were almost impregnable. Behind barbed wire, and in concrete redoubts, they could be taken only at a great sacrifice of man power—usually too great to be considered.

Something had to be done. The first method was that of intensive preliminary bombardment; that is, firing a stupendous quantity of shells into a given area. The prodigal use of shells for this purpose was staggering, running literally into the millions. Even this amazing use of ammunition, however, would have been warranted if consistent results had been secured. But they were not.

In the first place, the machine-guns were not completely obliterated, strange as this may seem. One notable example was the so-called Pomern Redoubt in the Ypres sector, which I examined in the fall of 1917. It is not far from Paeschaendale Ridge, and the fighting at this place was in full sight at the time. This emplacement was in reality a series of continuous "pill boxes" of reinforced concrete, laid out in an arc of about 45 deg., the chord of the arc being about 700 ft., and including

Digitized by Google

perhaps fifty machine-guns. It faced the British on a gentle slope, and the roof of the emplacement was perhaps 3 to 4 ft. above the ground. The ground all about had been completely pulverized by shell fire. Many shots had struck the redoubt, but it was still intact and serviceable. Repeated infantry assaults were made, but to no purpose. Tanks were then brought up, and two hours was all the time they needed. Being immune against machine-gun fire, they waddled right up to and over the emplacement and took it from the rear.

In the second place, the pulverizing of the ground made it almost impassable for infantry, and reduced the effectiveness of infantry assault. The difficulty of marching across this kind of ground cannot be described. It has to be done in person to be appreciated. Many hours of walking over such places has given me an increased respect for the endurance of the modern soldier. That he can advance miles through this terrain and then be ready to fight as he does is almost unbelievable.

In the third place, preliminary bombardment completely eliminates the element of surprise. It is like pausing in a prize fight and telling one's opponent that the next blow is coming on the point of his jaw, so he had best get his guard up.

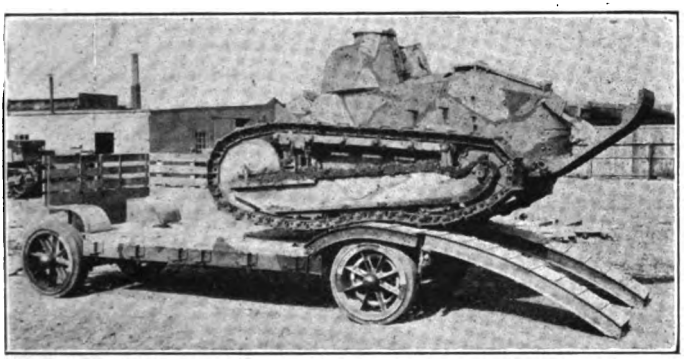
It is quite plain from the above that something new had to come, and come it did in the form of the tank. Fundamentally, the tank is simply a device that can come to close quarters with a machine-gun and destroy it or its crew. The armored motor car had been used to some extent prior to this war. It was confined, however, to fairly good terrain. Also, to armor it sufficiently to keep out armor-piercing bullets rendered it too clumsy. Increasing its size helped little, for it was still on wheels, and no wheeled vehicle would answer. The track-laying type of vehicle was, of course, old, but nothing had ever been constructed capable of negotiating the terrain of a modern battlefield.

The tank was the successful solution of this many-sided problem. It should be remembered that the tank is fundamentally a man killer and not a fort destroyer; also that its greatest defense against heavy artillery fire lies not in the armor it carries but in its own speed and mobility. This will be referred to more in detail later.

The number of fantastic ideas of supertanks sufficiently heavily armored to withstand artillery fire has been legion. Those who have been engaged in the solution of

Digitized by Google

the tank problem have been bombarded from above and below, from within and without, by the inventors of ponderous machines whose very "ponderosity" would be their own undoing. On this subject I speak feelingly, as I have been the target of a steady fire of criticism from those who did not understand the real issues.



A 6-Ton Tank Being Loaded on a Trailer

It may seem that this matter has been dealt with too much in detail, but it is my desire to get the real problem before you, as it is all too little understood. This was true even of the military authorities themselves in the early days, and the general public may be excused if it also is a little at sea.

It is doubtful if any new means of warfare has had so hard a time getting started and securing its just consideration as has the tank. Thanks, however, to its inherent value, it has steadily advanced and demonstrated its worth, and now is universally accepted as an indispensable arm of the service. Its future is secure. Its development has only just begun, and even those who have given it their individual attention feel that it is yet in its infancy and is capable of wonderful improvement.

Work Done by the English

To the English belongs the credit of producing the first practical fighting machine of this type. Their first attempt was along the lines of a heavy armored car. This was not successful. Then they turned to the track-laying type of vehicle. It should be said here that the first man,

Digitized by Google

probably, who suggested the idea of a large fighting vehicle, and who had a sufficiently clear grasp of the problem, was Lieut.-Col., now Brig.-Gen., Swinton, who had, several years before the war, broached the idea, and early in the war had argued its value and the tactics accompanying its use.

It remained for two others to make it mechanically practicable. Major Wilson of the British Army and Sir William Tritton, manufacturer of agricultural machinery, worked on the problem of the track-laying type, using the American type of track as a foundation. It seems to me that the really new feature of the large type of tank was carrying the track all the way around the body of the machine, and this design was the result of the joint labor of these two men. To negotiate wide trenches required a long machine. To climb over obstructions, particularly vertical walls, required great climbing ability at the front end. These requirements were both met in the long, rigid type of vehicle and the all-around track working up on a sloping front. These features, which were first combined by the two men mentioned, marked the design of a new type of machine, which was a practical success from the start.

We have now seen how the main idea was conceived, almost in its entirety, by Swinton, and how this idea was made mechanically possible by Wilson and Tritton. Many an excellent thing, however, dies right at this stage for want of some one with faith in its usefulness and persistence in its creation to "put it over," as we say. This part of the task fell to two other officers, Sir E. d'Eyncourt and Lieut.-Col. Sir A. G. Stern. Too much credit cannot be given to them, for in the early days ninety-nine out of every hundred men looked upon the scheme as chimerical. They were unable to get much backing, but their faith and persistence finally were successful.

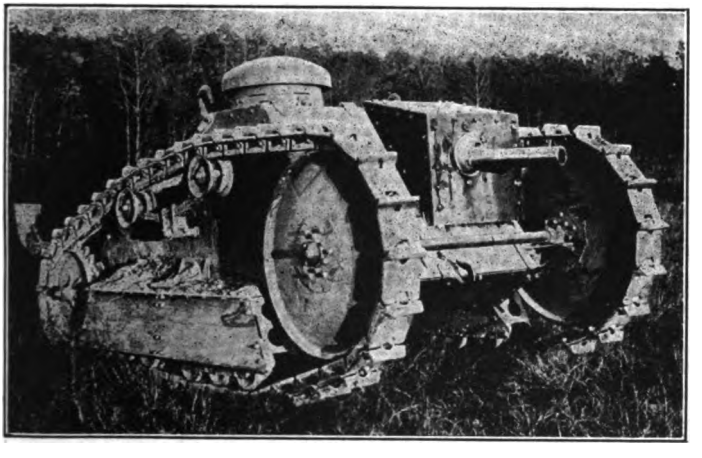
They were handicapped by the critical situation of English production resources at the time, and were allowed to use only such material as could be made available. Hence they had to use a heavy, stationary type of engine. A 100-hp. unit was the largest available. It was inadequate to give the best results, and many of the early difficulties of operation are traceable to lack of power. Some of the essentials of tank design were, naturally, not appreciated at first. Besides a lack of power, these earlier machines suffered from too great

Digitized by Google

a unit-ground-pressure. This caused them often to get mired in soft mud.

The Tanks in Action

As noted above, even the military authorities did not fully understand how to use the tanks. Usually, in the early days, they were sent "over the top" after an intense bombardment, which created a condition of terrain almost impassable for man, beast or machine. Consequently, while effective in some degree, their full value could not be attained. At Cambrai, in October, 1917, however, they had their first real chance. Here they were used in large numbers, and there was no preliminary bombardment. This fact meant surprise to the enemy and good terrain to operate on. The results were remarkable, and since then the most skeptical critic has had little to say. The subsequent reverse at Cambrai was in no wise connected with the employment of tanks. Two most interesting facts were the result of this attack. First, the saving



A 3-Ton Tank

in ammunition—which would have been used according to the old system in this one engagement—equaled the entire expense of the whole tank development up to that time. The tank squared financial accounts in this one engagement. Second, the finest, and supposedly the most impregnable, section of the famous Hindenburg line was crossed and captured with ease.

The French had been busy, too, during this period.

Digitized by Google

Only a little later than the English, they started developing a tank. They completed and put into the fighting line two machines, one made by the Schneider Company, and one by St. Chamond, the former being mechanically driven, while the latter was of the gas-electric type. Both were equipped with one 75-mm. gun and several machine-guns in addition. These two machines were not, however, of the type of the English tank, with its all-around track. They were practically overgrown caterpillar tractors, with the necessary equipment mounted thereon. The bodies, in each case, extended, both fore and aft, considerably beyond the ends of the track proper, and also extended over the top of the tracks. This construction imposed serious limitations on the ability of the machines to negotiate bad terrain. Like the English tanks, they were somewhat lacking in power, which, taken together with the overhanging body features, seriously curtailed their action.

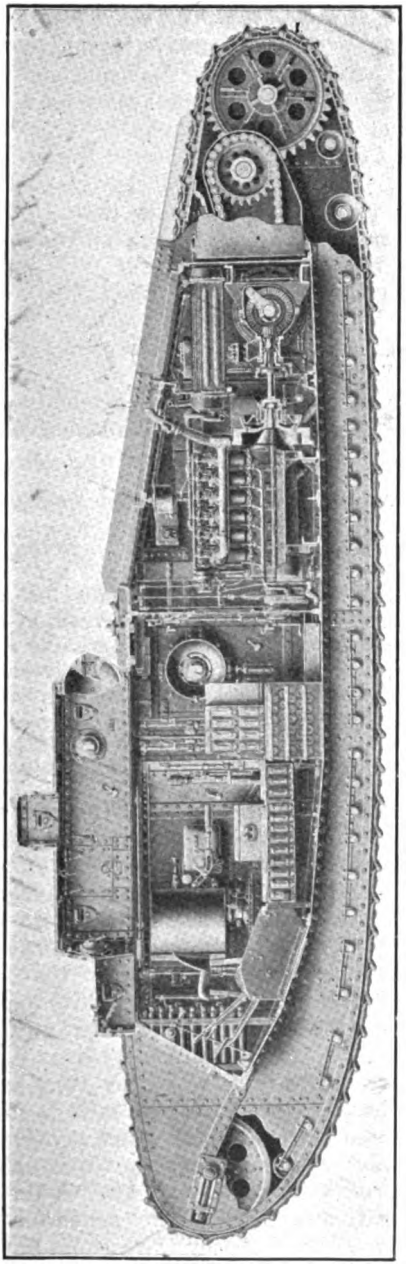
The French quickly arrived at the opinion that large tanks would not be successful, although subsequent developments with the English tank showed that in this respect they were much mistaken. In many ways, however, their decision was fortunate, in that it led them to turn their attention at once to the construction of a smaller machine. The result of this decision was the development by Louis Renault of a small two-man tank capable of considerable speed and possessed of a very fair amount of power per unit of weight. In many ways, the small Renault tank is a very remarkable machine. It will cross trenches up to 5 or 6 ft. wide. It will climb grades of one in one, or 100 per cent. It will hold a speed on a level of about 5 miles per hr.

These tanks were built of two kinds, one equipped with a 37-mm. one-pounder semi-automatic gun, and the other with a Hotchkiss machine-gun. These were used in about a 50-50 ratio in actual fighting.

The tracks were spring suspended, which enabled a speed of 5 or 6 miles per hr. to be easily maintained without serious detriment to the machine. In fact, some of these machines, since equipped with more powerful engines, have successfully made 10 miles per hr. across open territory.

It is very natural that the experience of the French with their first large tank should have convinced them that the small unit was the solution of the tank problem. It was equally natural that the success of the British

Digitized by Google



SIDE VIEW OF THE MARK VIII TANK

Digitized by Google

with their large tank should have, at first, convinced them that the big type was the solution. The results were extremely fortunate, in that they gave to the Allied fighting forces two kinds of tanks.

When the American Army entered the war both of the above lines of action were sufficiently well defined, so that the Americans decided to use both kinds, namely, a large and a small tank. For our small tank we adopted the Renault type. For our larger unit we accepted a modified design of the large British tank, the design being a production of British and American ordnance engineers working jointly in the winter of 1917-18 in London.

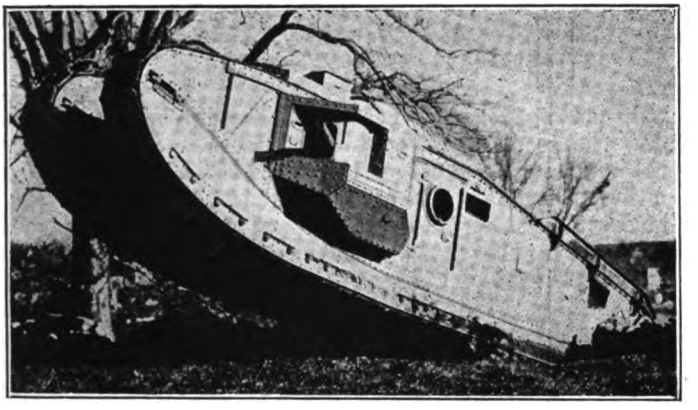
Certain fairly well-defined essentials have gradually appeared in the matter of tank construction. They are as follows:

(1) Not less than 10 hp. per ton of weight should be provided
(2) The pressure per square inch between the track and the ground should not exceed 5 lb. per sq. in.
(3) The tank should be entirely controlled, so far as its mechanical operation is concerned, by one man
(4) The tank should be capable of making a speed of not less than 5 miles per hr. on a level, and anything over that greatly increases the fighting ability of the machine
(5) The only armor is that required to give protection against armor-piercing machine-gun ammunition

A great deal has been said and thought about tanks with heavy armor, 2 and 3 in. thick, as a protection against moderately heavy artillery fire. Actual fighting conditions, however, have proved conclusively that tanks are rarely struck by direct artillery fire when in motion in action, as they do not present a very large target, and then only a moving one. Nearly all of the tank mortalities resulting from direct artillery hits have occurred when tanks were standing still, either awaiting orders or unable to move for mechanical reasons. Thus it has been demonstrated very conclusively that against artillery fire the best protection of the tank is its own speed and mobility and not the armor which it carries.

It is very doubtful whether any supertank will be of a great deal of value, although one would be rash to make too positive a prediction. Anti-tank cannon, so called, have been developed by the enemy, but have never succeeded in doing anything serious. The super-machine

Digitized by Google



THE MARK VIII TANK CLIMBING A STONE WALL

gun, or a heavy caliber rifle, up to perhaps ½-in. caliber, is the most serious attacking force that the tank has to defend itself against. Experiments on armor plate, however, indicate that defense against guns of this type can ultimately be secured with armor plate little thicker, if any, than that used at the present time. It might be stated here that the development and resisting power of light armor plate have recently been most gratifying, and indicate remarkable results possible in the near future.

The future development of the tank presents great possibilities. It must be fast, light on its feet, so to speak, and have large radius of action. It would appear that three sizes of tanks would be required:

(1) The large one. This must be able to cross any trench that can be manned by the enemy. It is quite probable that large tanks will entirely preclude trench warfare. If so, the whole strategy of war will be changed. These large tanks will not be required in great numbers, but their presence is imperative

(2) A medium-sized machine for following through after the large tanks and putting up a stiff fight. These machines must be tough fighters, and be present in considerable radius of action

(3) A small machine that will carry a driver and one gunner. It must be as small as possible to carry the two men. It must be simple in construction and very fast. It should be used in vast numbers, and be, in fact, a mechanical machine-gun cavalry. A thousand of these machines breaking through a

Digitized by Google

gap made by their big brothers would completely disorganize the enemy's rear and produce a disaster

In closing, let me repeat: The tank is one of the few new things produced by the present war. It is only in the nursing-bottle stage. It will work a complete revolution in methods of making war. The side having the largest number of good fast tanks of the correct kind will always win. Its development has been almost a romance, and the future contains vastly more for it than the past.

THE. DISCUSSION

CHESTER S. RICKER:—At what speed were the 35-ton tanks of the Mark VII type supposed to operate? Their horsepower per ton was very much in excess of the figure which you suggest as desirable. Was this excess used to gain speed or to increase the mobility of the unit?

LIEUT.-COL. H. W. ALDEN:—The Mark VIII tanks were to operate at 5½ miles per hr. with the engine running at 1400 r.p.m. The horsepower which I stated as being desirable was at least 10 hp. per ton of weight. These tanks weigh about 35 tons and the engine will develop about 350 hp. Consequently the ratio is about what I gave.

MR. RICKER:—Are not the stresses imposed upon the framework of the large type tank enough to wrench it until it becomes loose? I appreciate that the design of these machines employs the armor plate that forms the hull as the main framework upon which the mechanism and track are mounted. It would seem that in crossing trenches or shell craters diagonally the box-shaped frame would be twisted just like a cardboard box heavily weighted and suspended at two points. It would tend to buckle. Under these stresses how long do the tanks last in service when they are not destroyed by direct hits?

LIEUT.-COL. ALDEN:—Very severe tests were made on this tank to determine distortion. It was jacked up and balanced at the center; it was jacked up at two extreme ends, and it was jacked up at opposite corners, and practically no deflection or deformation could be found. There is no reason why the life of these tanks, due to this particular feature, should not be practically indefinite.

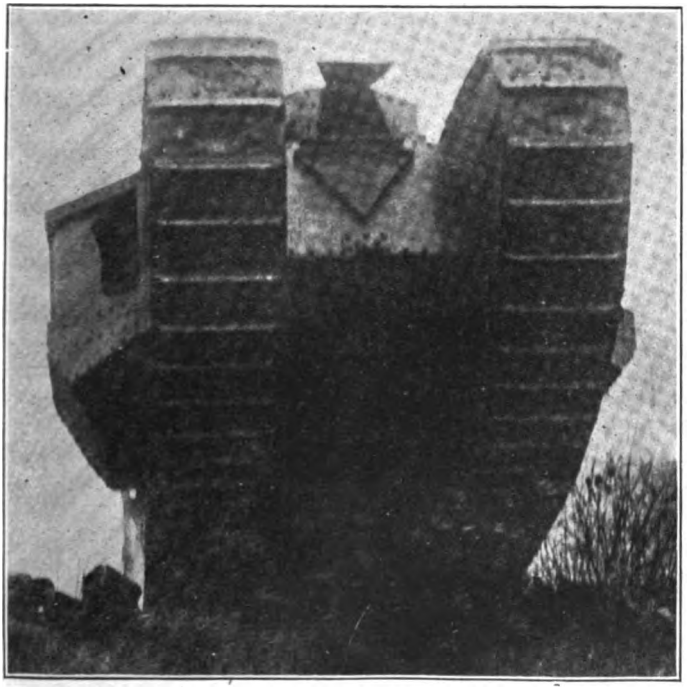
MR. RICKER:—With the hull type of design, which I note has been used by the British not only on their tanks but also on their towing and load-carrying tractors, is there greater immunity from loading of the track

Digitized by Google

and the subsequent breakage such as is encountered on tractors of the more open type of track support? The military tractors that employ the track frame like the 5-ton model and also the spring-supported tracks like those on the 6-ton special tank had considerable trouble from track breakage when going over gravel or similar terrain. How did the breakage of track on these compare with that on the hull-type tanks in which there seems to be almost no chance of track loading?

LIEUT.-COL. ALDEN:—In regard to breakage of tracks, it can be stated that the British had considerable difficulty. Their tracks, however, were made of steel castings riveted to pressed steel shoes, and the steel castings wore out. Track links on the Mark VII machine were heat-treated forgings, and the model machine, which ran something like 100 miles on a hard surface, showed absolutely no wear. It was run over rocks at full speed to break the track, if possible, but no damage resulted.

MR. RICKER:—What were the difficulties encountered



A FRONT VIEW OF THE MARK VIII TANK CLIMBING

Digitized by Google

with the gas-electric machines? On account of the large reduction necessary between the engine and the track drive sprockets it would seem that there might be a decided advantage in the electric drive.

LIEUT.-COL. ALDEN:—The difficulty with the gas-electric system of propulsion is that it has not the quickness of response, the necessary punch and the necessary efficiency at extreme overloads. There is no difficulty in getting the requisite gear reduction mechanically, and the total weight of the transmission is very much less with the mechanical than with the gas-electric.

MR. RICKER:—How were the electric machines controlled? Were separate controllers used for each track like the separate clutches used on the Renault-type tank or planetary gearing as on the large tanks?

LIEUT.-COL. ALDEN:—Special switches and controllers were used on our experimental machines for each track.

MR. RICKER:—How much faster were the tanks with the spring-supported track rollers of the Renault design than those with the non-spring-supported track rollers on the hulls of the large tanks? I have noticed that in the tractor field the tendency has been away from the completely articulated track like Renault and toward the English rigid type. In one very long unit, the Mark VII tractor caisson, three track roller frames were used and then abandoned in favor of one very long one and a short one, combined or connected with a hinge. Also Schneider seemed to consider the single rigid track frame more desirable than the Renault type. Which, in your experience, seems to be the better, or is there some particular field in which one works better than the other?

LIEUT.-COL. ALDEN:—There is no question but that very high speed necessitates spring suspension of some type. Adequately suspended on a peculiar form of spring suspension, a certain heavy English tank was actually driven on a highway at 28 m.p.h. without any damage. This, of course, is an extreme case, but I believe that where the speeds exceed 5 or 6 m.p.h. it is necessary to have a spring-suspended roller.

Digitized by Google

AUTOMOTIVE ORDNANCE APPARATUS

By Lieut-Col William G Wall, U S A[1]

THE author presents a brief description of the design of some of the principal vehicles used in motorizing the artillery, as developed by the Ordnance Department. A few of the vehicles are described, including gun mounts that were being developed at the time of the signing of the armistice. The relative merits of the different types of equipment are discussed.

It is not believed necessary before members of this Society to go into the merits and advantages of motorizing the artillery, for to them the reasons will appear obvious.

A brief description will be given of the different vehicles developed and used and the conclusions reached regarding their relative merits will be stated.

Nash and F W D Trucks

It was early decided by a military board appointed for the purpose that the trucks used for artillery purposes should be of the four-wheel-drive type, and, as it was not considered advisable to wait to develop an ideal truck of this type, two makes of this type truck then on the market were adopted, one being the 3-ton F.W.D., and the other the 2-ton Nash Quad. On these two types of trucks were placed a number of the different bodies necessitated by the various uses to which they were put.

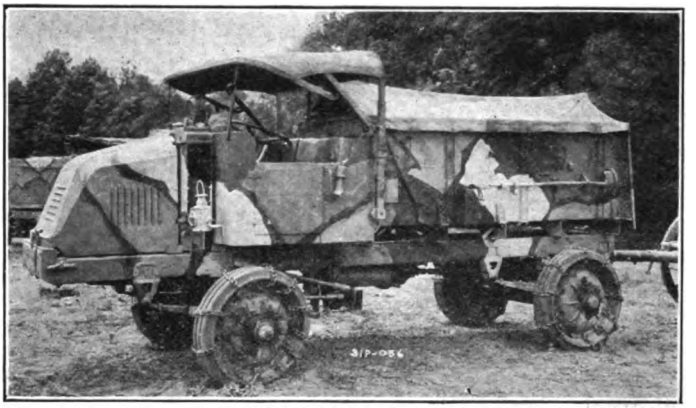
The engine used in the 3-ton chassis was a four-cylinder, 4¾-in. bore by 5½-in. stroke; the 2-ton having a four-cylinder L-head type engine, 4¼-in. bore by 5½-in. stroke. An Eisemann magneto was used on each of these trucks. The wheelbase of the chassis in both cases was 124 in., and steel wheels with tires 36 by 6 in. were used. The gear reduction on low speed for the 3-ton was 36 to 1, and on the 2-ton, 42.3 to 1.

Ammunition Body

A steel body was designed to carry packing cases for seven different sizes of ammunition and equipped with a chain hoist to load the heavier calibers of this ammunition. The steel used in this body was No. 10 gage. Re-

[1]Motor equipment section, engineering division, Ordnance Department, Washington.

Digitized by Google

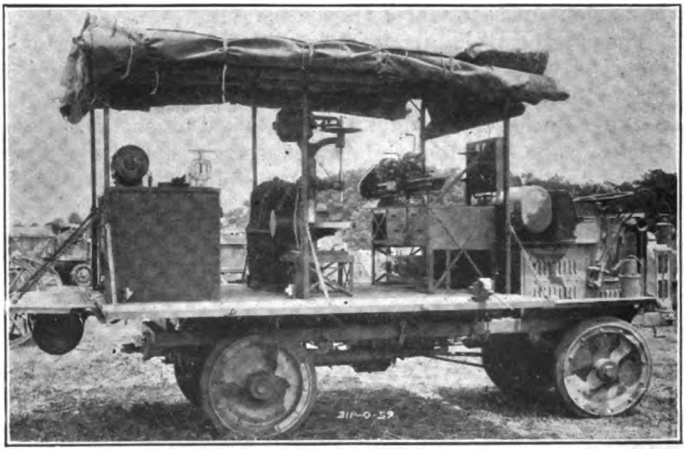


STANDARD ORDNANCE 3-TON TRUCK WITH AMMUNITION BODY

movable seats were also provided for carrying the personnel. A complete set of tools was attached to the sides of the body.

ARTILLERY REPAIR TRUCK

The artillery repair trucks used the type of chassis mentioned above and consisted of a small machine shop with machine tools driven by electric motors, the power being secured from a stationary four-cylinder engine,



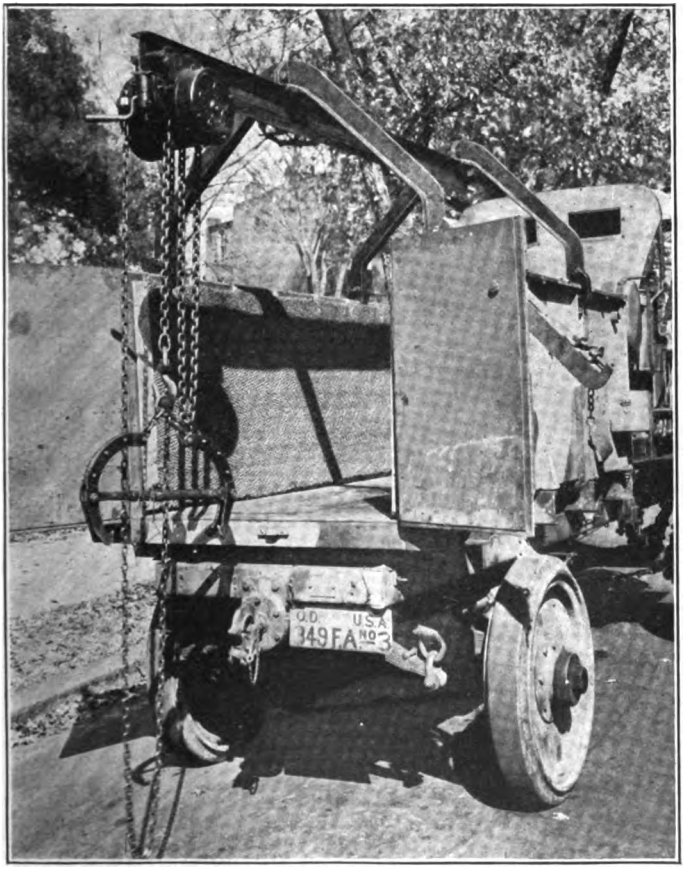
ARTILLERY REPAIR TRUCK

Digitized by Google

2⅝ in. by 4 in., and a 4-kw., 110-volt multipole generator with complete switchboard.

The tools in this machine shop consisted of the following:

9-in. lathe, with milling and gear cutting attachment
Vertical drilling machine for drills up to ⅝ in. diameter, driven by a ½-hp. motor
Bench grinding machine, with two emery wheels, electrically driven
Air compressor set with motor complete
Oxy-acetylene welding and cutting outfit
Two machinist's and one pipe vise
Portable drilling machine



AMMUNITION HOIST AND HEMP LINING FOR BODY

Digitized by Google

Acetylene cylinder, besides a large assortment of small tools and necessary work benches.

Nearly a thousand of these artillery repair shops were completed; also a number of heavy mobile repair shops mounted on trailers were made.

Artillery Supply Truck

The same chassis was used also for the artillery supply trucks. This truck consisted of an open body with a number of chests containing the proper tools, which included: Carpenter's tools, saddler's kit, chain block, grindstones, spare parts for optical instruments and optical repair equipment, cleaning materials and a forge outfit in addition to a chest for springs and fluids used for gun recuperators.

The artillery supply truck was an auxiliary to the artillery repair truck and the contents of the chassis were determined by the organization in which this truck was used, for example, the size, type of gun, etc. These trucks also carried spare wheels and all the necessary spare parts for the guns and caissons.

Equipment Repair Truck

The equipment repair truck consisted of the four-wheel-drive chassis with body, carrying the necessary equipment and machines for the repair of all equipment. The cabinets were made of sheet steel, containing all necessary small tools and spare parts required. Among the tools was a heavy Singer sewing machine and a Champion stitching machine, besides several vises. In fact, this truck carried complete equipment for the repair of all leather and canvas goods and small arms. All machines on this truck were pedal-driven.

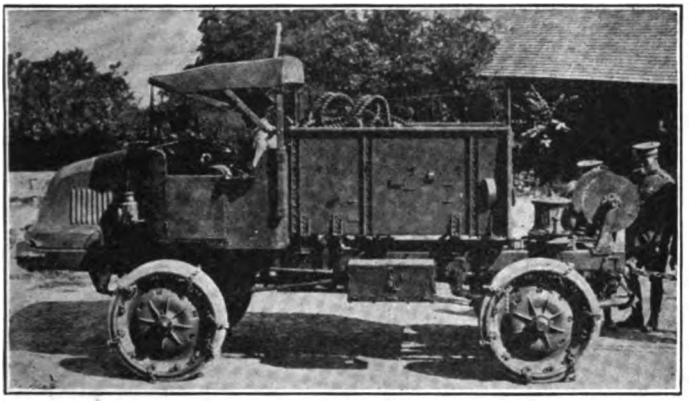
The light repair truck was for emergency repair work, and consisted of a special steel body on a Dodge chassis.

3-Ton Truck and Artillery Wheeled Tractor

As soon as the procurement and production of two makes of four-wheel-drive truck were well enough under way to take care of all immediate needs, the design of a four-wheel-drive ordnance truck was started. Later certain changes were made in the truck for the purpose of converting it into a wheeled tractor.

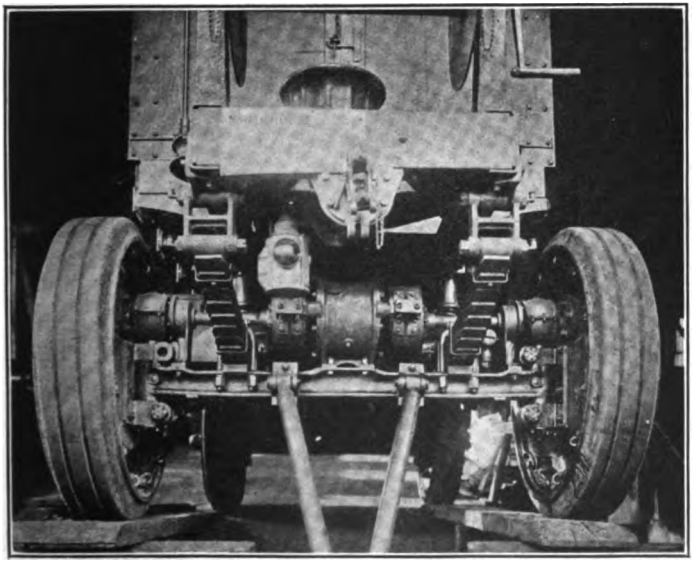
A four-cylinder 4¾-in. bore by 5½-in. stroke Wisconsin engine was used, as it was in production and nearer the right size and weight than any other.

Digitized by Google



ARTILLERY WHEELED TRACTOR

The Model B truck transmission, with four speeds forward and reverse and M. & S. locking differentials were used, the axles themselves being of new design with internal-gear drive, the truck using 36 by 7-in. tires and the tractor 40 by 8-in. tires. An Eisemann magneto with impulse starter was used for ignition. The



REAR AXLE OF THE ARTILLERY WHEELED TRACTOR

Digitized by Google

total weight of the truck was 10,500 lb., with a normal carrying capacity of 3 tons.

As a truck this vehicle had two-wheel-steer, but as a tractor, in order to have short turning radius, a four-wheel-steer was used, giving it a turning circle of 35-ft. diameter. As a truck the gear reduction was 68 to 1 on low and as a tractor 86.7 to 1 on low.

This vehicle is made so that any of the bodies previously described can be put on. When used as a tractor a winch was mounted at the rear end and a short body was provided for carrying sufficient load to give traction; also all necessary tools, etc. The winch provided on this tractor was designed so as to be capable of breaking 1½-in. Manila rope, equivalent to a load of about 18,000 lb. The drawbar pull of this and other tractors is given in the table on pages 78 and 79.

Reconnaissance, Machine Gun and Staff Observation Cars

It was found necessary to adapt a chassis for the use of the reconnaissance, machine gun and staff observation cars. The White Tebo chassis and the Commerce 1-ton chassis were used for this work. The former was used for the staff observation and reconnaissance cars and the latter for the machine gun car.

The White chassis used was the regular 1-ton, except for a larger engine. This was of the four-cylinder type, 4¼ by 6⅜ in. The chassis had 140-in. wheelbase, with four speeds forward and reverse, geared up on high speed.

For the staff observation car a regular seven-passenger chassis might have been used, but on account of the rough service to which it was subjected and the necessity of carrying certain observation instruments, it was deemed expedient that a special body be designed for this purpose. This body seats eight passengers comfortably and contains a number of lockers in which the compass, telescopes, protractors, plotting boards, aiming circle, flashlights, etc., are carried in addition to a number of other instruments necessary for artillery observation.

Track-Laying Tractors

The conclusion was reached in the early months of the war that it was necessary to have tractors to haul some of the heavy guns over almost any type of terrain. A number of different types were tested for this purpose

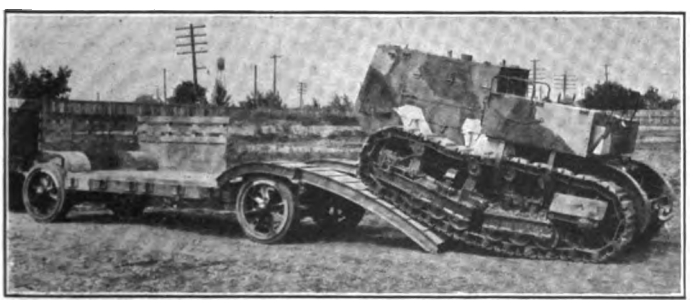
Digitized by Google

and the decision reached that the track-laying type was best suited to the work. As the British had been using a few of the Holt caterpillars some of these were secured, namely: the 75 hp. or 15-ton and the 120 hp. or 20-ton, and the Ordnance Department started work immediately upon improved types of these track-laying vehicles to produce something more suitable for the Army's needs.

It was deemed necessary that the front wheel as used on most of the heavier caterpillars be dispensed with; also that the engine and vulnerable parts be covered with armor plate. On account of the complaints made by the French that the caterpillars tore up the roads, it was decided that smooth-track caterpillars should be used, and the grousers made attachable, the latter to be put on only when going over shell-torn areas and where they would not in any way damage the roads.

Several of these tractors were designed, namely: the 10, 5 and 2½-ton. The 10-ton tractor embodied most of the features of the Holt caterpillars, and, while it was a big improvement over anything which had preceded it, was very similar in a great many respects to other designs. The 5-ton departed very materially from any previous designs, and the 2½-ton was entirely different from any tractors previously built, although it possessed some of the Renault features.

The 10-ton artillery tractor has a four-cylinder, valve-in-the-head engine, 6½-in. bore by 7-in. stroke, cylinders cast separately; 55 hp. at 600 r.p.m., and uses a K. W. high-tension magneto with impulse starter. The transmission is of the sliding gear type, three speeds forward and one reverse, with direct drive on second speed. Both the main clutch and the steering clutches are of the dry-plate multiple-disk type. The main frame is a steel



10-Ton Artillery Tractor Mounting 10-Ton Trailer

Digitized by Google

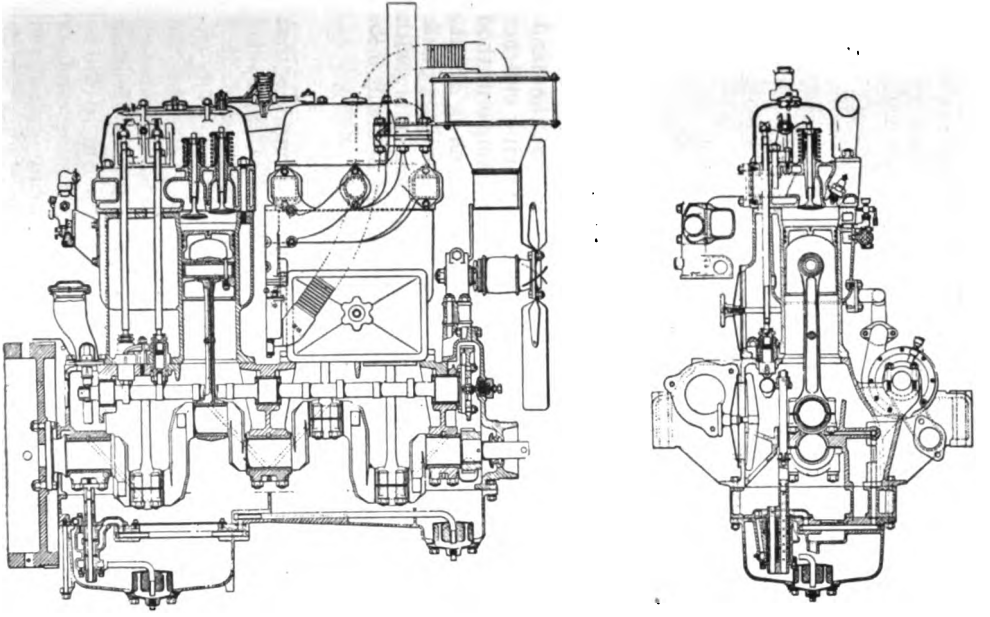
casting, and the roller frames are built up of channel steel. These rollers are used on each side, and all are fitted with Hyatt roller bearings. Weight, about 21,000 lb., with pressure of 7½ lb. per sq. in., the width of the track shoe being 15 in.; tread of track center to center 61 in. The maximum speed of this tractor is close to 6 miles per hr. The capacity of the gasoline tank is 46 gal.; the drawbar pull on direct drive about 5000 lb., and on low gear 8000 lb. A cast-steel shoe is used with smooth tread arranged to receive grousers which are bolted on. Armor is used to protect the engine and the fuel tank, and, as on all artillery vehicles, a latch pintle is provided. This tractor is principally used to pull the 155-mm. gun.

The 5-ton artillery tractor was designed primarily to pull the 9.2-in. howitzer, which is divided into three loads, thus requiring three of these tractors to pull one gun. It was later used to draw the 6-in. howitzer in one load.

The engine is a four-cylinder, valve-in-the-head type, 4¾-in. bore by 6-in. stroke, cylinders cast in pairs, developing about 56 hp. at 1200 r.p.m.; Eisemann magneto, with impulse starter, is used, and a Schebler carbureter provided. Both the main and steering clutches are dry-plate, multiple-disk type. The frame is cast steel and the roller frames are built up of channel steel. Track shoes are cast steel, 11 in. wide. The transmission has three speeds forward and one reverse, direct drive on second. The gasoline tank has two compartments, each holding 12 gal. The Bendix type hand-starter is used. An interesting lubricating system is used in the engine. It is of a type which prevents excess oil at the rear cylinders when ascending a hill. A dry crankcase is maintained, as all oil which flows off from the crankcase is pumped out of the oil-pan and delivered to the oil reservoir, from which it flows again under pressure through the engine bearings. A triplex geared oil-pump is used to accomplish this. An ingenious spring radius rod is used on the track frames which very materially aids in the proper operation. The pressure on the ground is about 5 lb. per sq. in.

It was originally intended that the telephone and fire control cable be carried on a truck, but after extensive experiments it was decided to use the regular six-horse reel and to make a small 2½-ton track-laying tractor to draw it. Approximately two months before the armistice

Digitized by Google



FRONT AND END ELEVATIONS OF THE ENGINE USED IN THE 5-TON ARTILLERY TRACTOR

Digitized by Google

was signed it was decided to motorize the 75-mm. guns and these tractors were designated to pull them.

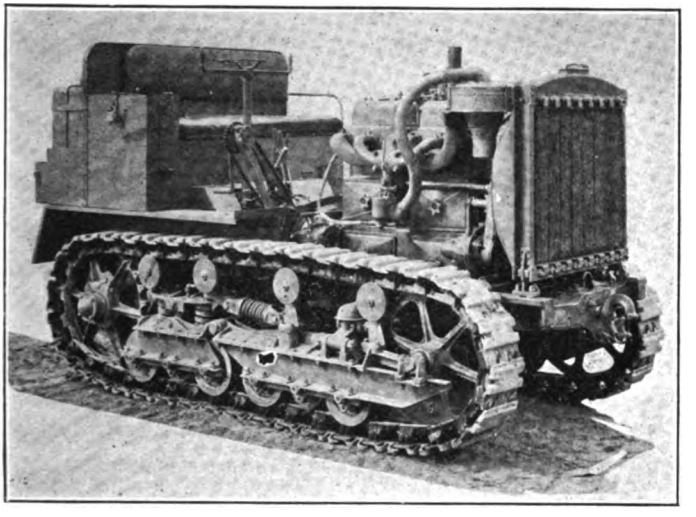
An eight-cylinder L-head V-type engine was used with 3⅛-in. bore and 5⅛-in. stroke, with about 70 hp. at 2600 r.p.m. This will be recognized as the Cadillac engine. A three-speed selective transmission with direct drive on high speed was used and through this power was transmitted in about the usual way through a secondary transmission with steering clutches of the multiple-disk type to the track sprockets. The main frame of this tractor was built up of angle iron. The roller frames are the Renault type with four rollers on each side. Track shoes are of cast steel with bolted-on grousers. Armor is placed over the engine and tank. A regular ordnance pintle is supplied at the rear end. While the normal high speed of this tractor is 12 miles per hr., it will run 20 miles per hr., pulling a 75-mm. gun over level going. This tractor has a drawbar pull of approximately 4000 lb. on low gear. The steering control on this tractor is a little different from that of the others in that the hand-steering lever not only throws out the steering clutches but also puts on the brakes, making a very simple method of steering. The capacity of the gasoline tank is 20 gal., with pressure feed. There is also an auxiliary tank holding 5¾ gal., located under the engine armor, with gravity feed. The pressure on the ground is about 5 lb. per sq. in.

Mark VII Tractor Caisson

One of the latest and most interesting designs is that of the Mark VII tractor caisson. This is a caterpillar cargo-carrier and while rated at a carrying load of 3 tons can carry 5 tons up a 45 per cent grade. The engine used in this tractor is the same as is used in the 5-ton artillery tractor, four-cylinder, 4¾-in. bore by 6-in. stroke. The total gear reduction is 100 to 1 with a maximum speed of approximately 6 miles per hr. It will be noted that the roller frame on this vehicle has nine rollers and is divided into two parts with a spring radius rod very similar to that of the 5-ton tractor. This vehicle has six speeds forward and two reverse. The pressure on the ground is about 7 lb. per sq. in.

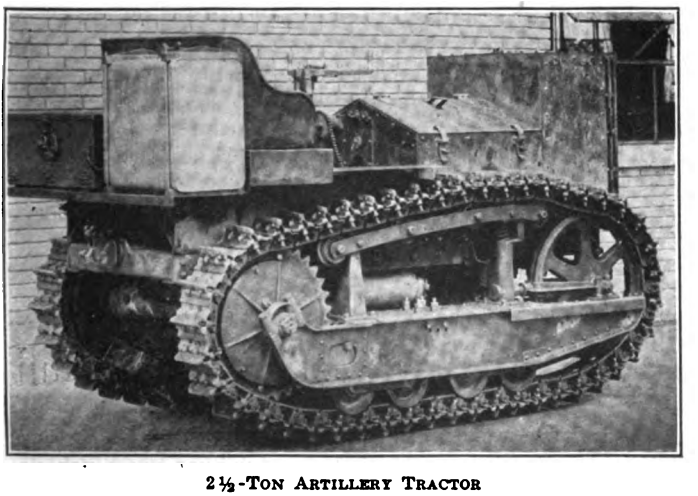
One of the most interesting developments of the war was the placing of both light and heavy field guns on track-laying mounts. The 8-in. howitzer was placed on a track-laying vehicle giving a total weight of 55,000 lb. and capable of a maximum speed of about 4 miles per

Digitized by Google



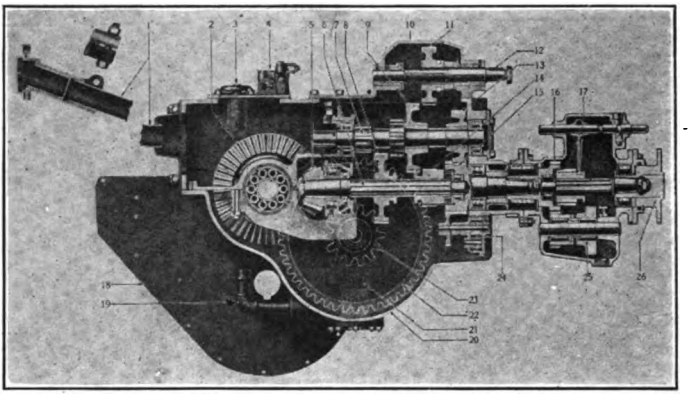
2½-Ton Artillery Tractor Without Armor or Top

hr. From the artillery standpoint this was a very advanced piece of work as it allowed the gun to be run over any kind of terrain and brought into action within a couple of minutes after arriving. A mount was also made for the 75-mm. field gun by placing it on one of the 2½-ton tractors, which was modified to suit the re-



2½-Ton Artillery Tractor

Digitized by Google



SIDE VIEW OF TRANSMISSION USED IN THE MARK VII TRACTOR CAISSON

1 Oil filler tube.
2 Bevel ring gear.
3 Breather.
4 Steering clutch control cams.
5 Bevel pinion.
6 Main pinion shaft.
7 Countershaft reverse gear.
8 Low and reverse sliding gear.
9 Countershaft, second speed gear.
10 Winch transmission case.
11 Winch sliding gear.
12 Winch spline shaft.
13 Countershaft driven gear.
14 High and second sliding gear.
15 Main drive pinion.
16 Main drive coupling gear.
17 Countershaft sliding gear.
18 Sprocket sleeve gear plate.
19 Oil level stand pipe.
20 Lower transmission case.
21 Oil feed tube to pump.
22 Intermediate gear.
23 Intermediate pinion.
24 Oil pump assembly.
25 Auxiliary countershaft.
26 Coupling.

quirements. This gun was capable of traveling over almost any rough ground and attained a speed on the level of 16 miles per hr.

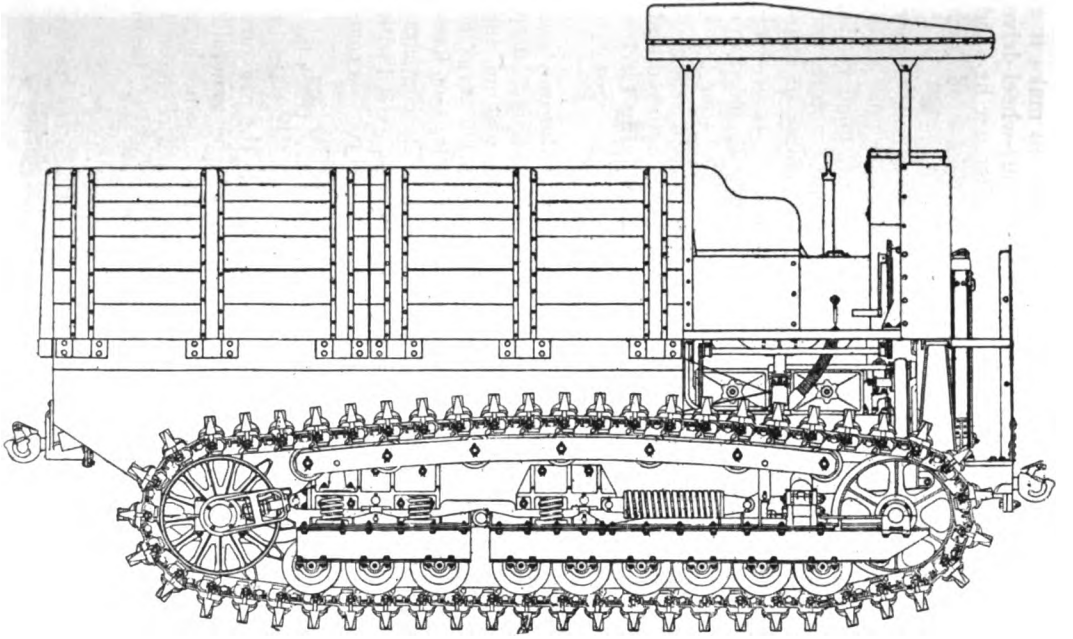
Two-Wheel and Four-Wheel-Drive Vehicles

There has been considerable controversy, especially in military circles, in regard to the relative advantages of the four-wheel-drive and the two-wheel-drive types of vehicle. There is no question in my mind that for good road hauling where deep holes are seldom encountered, and the vehicle does not have to get off the road, the two-wheel-drive truck is a more efficient vehicle for cargo carrying than the four-wheel-drive type, and is also preferable on account of the economy of operation and the lower cost of upkeep. On very bad roads, however, though this gives very narrow limits, the four-wheel-drive truck has considerable advantage over the two-wheel-drive.

The Wheeled Tractor

Used strictly as a tractor for work confined entirely to the roads, the four-wheel-drive rubber-tired vehicle

Digitized by Google



SIDE ELEVATION OF THE MARK VII TRACTOR CAISSON

Digitized by Google

has many advantages over any other type and it is believed there is nothing that can compare with it. It is not considered that the two-wheel-drive rubber-tired tractor has sufficient adhesion to the roads to make it a very important factor. The rubber-tired four-wheel-drive tractor has all the necessary speed, 15 miles per hr., and in this respect is much better than the steel-tired farm tractor of any type.

The friction coefficient of rubber tires giving proper adhesion to the road surface, with the proper gear ratio, makes the drawbar pull of this vehicle, for good roads, nearly the equivalent of the track-laying tractors and preferable to the steel-tired tractors. Economy of operation is greater than with either the track-laying or steel-tired vehicles. The cost of upkeep, considering speeds obtainable, is much less than with either of the other types. This vehicle has its limitations, however, for while it can be used on rather poor ground it is not believed that it compares in this respect with the track-laying tractor.

Track-Laying Vehicles

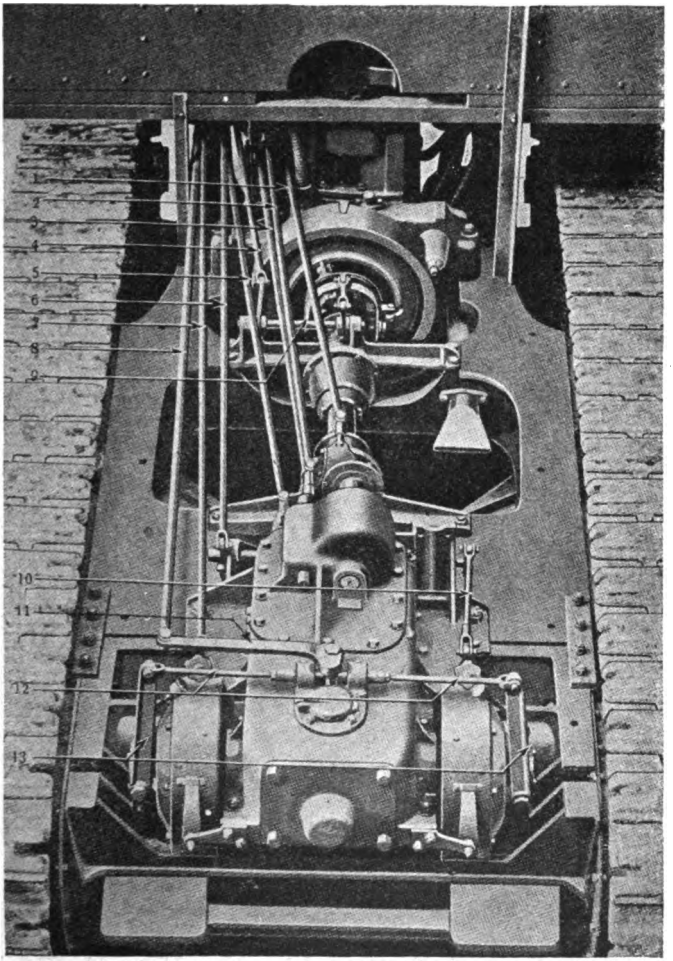
The track-laying or caterpillar tractor is the only one which can be seriously considered in going through deep sand and over very soft or rough and cut-up ground, and it has been fully demonstrated that no other type of vehicle can compare with it in this respect. Its use, however, is limited to work of this kind, due to its comparatively slow speed and expense of upkeep as compared with the rubber-tired tractor; also its high initial cost as compared with steel-tired wheeled farm tractors.

The main difference, however, between the track-laying vehicle and the wheeled vehicle, when the latter tracks perfectly, like the four-wheel-steer, is due to the pressure per square inch exerted on the ground, it being generally very much less for the former and in practice somewhere between 4 and 9 lb. per sq. in. Also, the track is well anchored by the grousers, and the sprocket, of those

Parts of Mark VII Transmission

1 Shifting rod for auxiliary transmission.
2 Shifting rod for winch transmission.
3 Shifting rod for low and reverse.
4 Control rod for master clutch.
5 Shifting rod for direct and high.
6 Brake rod for right steering clutch.
7 Brake rod for left steering clutch.
8 Steering control drag link.
9 Master clutch cross shaft.
10 Clutch brake rod.
11 Bell crank for steering clutches.
12 Steering clutch push rods.
13 Steering clutch shifter fork.

Digitized by Google



View Looking Up at the Transmission Used in Mark VII Tractor Caisson

(See Opposite Page for List of Parts)

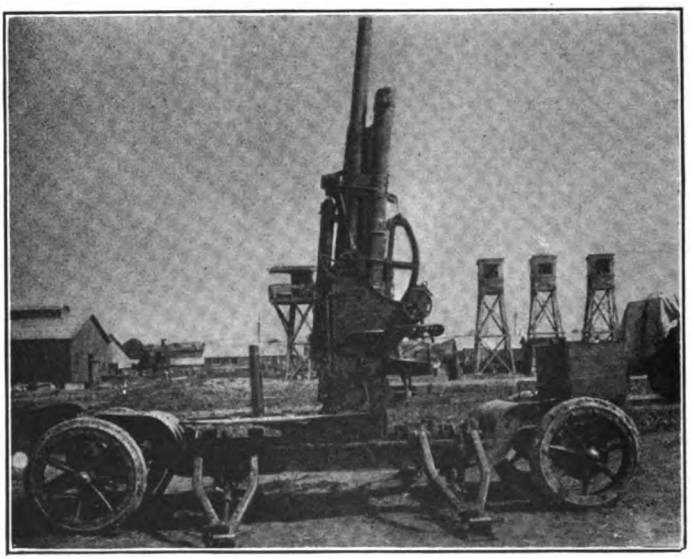
Digitized by Google

using sprockets, driving on the track prevents all slipping.

A track-laying vehicle necessarily weighs more than the wheeled type. This is due to the number of rollers running on the track and the weight of the track itself. At the beginning of the war very little attention had been devoted to the fact that to make a successful track-laying vehicle it was necessary, on account of the impossibility of the track stretching to any extent, to have roller frames so that whenever foreign substances, such as large rocks or limbs of trees, were caught in the sprockets, the length of these frames would be shortened sufficiently to prevent breakage of the track. This was worked out very nicely on the 5-ton tractor by the use of a spring radius rod; also the roller frames for track used on the 2½-ton tractor were developed so that a vertical coil spring was used to allow for this compensation.

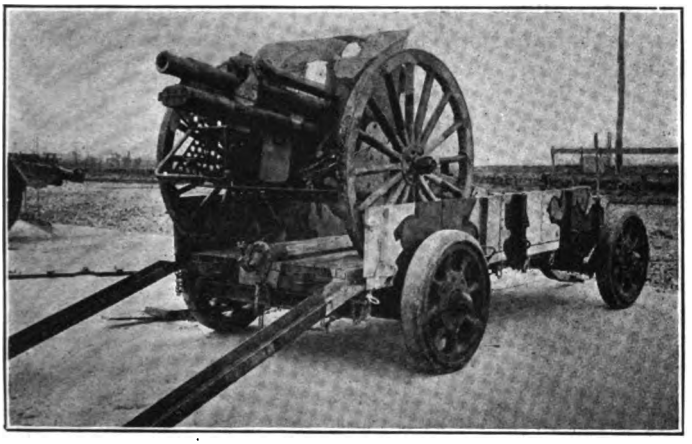
Trailers

Several different types of trailers were designed, one of which was a 10-ton unit for hauling the small tanks over good roads at comparatively high speeds; also a trailer for carrying a 75-mm. field gun, and some smaller



3-In. Anti-Aircraft Gun on Trailer

Digitized by Google



75-Mm. Gun on Field Gun Trailer

trailers in addition to the one used for the 3-in. anti-aircraft gun.

Two or Four-Wheel Steer

Experience has proved rather definitely that a vehicle with four-wheel steer cannot easily be kept on the road at high speeds and 15 miles per hr. is about the limit. For this reason all cargo-carrying trucks should be two-wheel steer, although the four-wheel steer has considerable advantage in rough going and in turning corners, on account of rear wheels tracking with front wheels. The wheeled tractor, however, due to the fact that 15 miles per hr. is the maximum speed generally required, and 95 per cent of the time it is running very much more slowly, and due to the great necessity for short turning radius, allowing it to maneuver easily in a limited space, must either be of extremely short wheelbase, which is not always practical, or have four-wheel steer, that is, both front and rear wheels should steer. The new artillery wheeled tractor is of this type, as are also the Renault and Latil tractors used by the French.

A two-wheel steer trailer running on four wheels cannot readily be backed into any particular desired location. It is somewhat easier to do this if it has four-wheel steer, though as this is rather complicated for a trailer, it has been found desirable in a number of cases to have the rear wheels locked in position but capable of being steered by hand by the use of a bar.

Digitized by Google

Due to military reasons it was necessary for the army to use a certain number of trailers, some of which have been described, and the use of these trailers in several instances worked out very well.

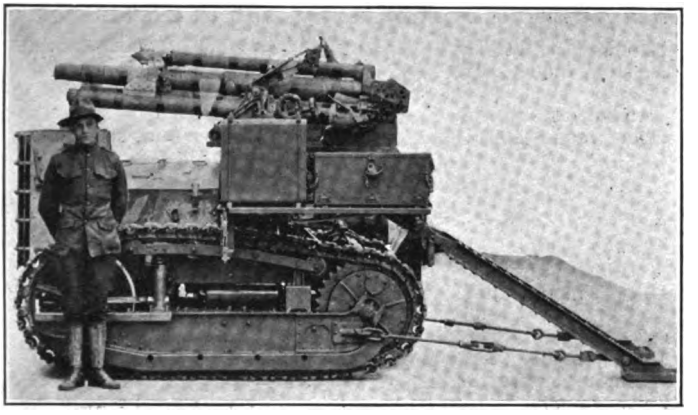
The results of tests show that on hard roads, level going, or with very slight grades, the trailer has a number of advantages over carrying the load on top of the tractor; also where the bulk of the cargo is very great in proportion to its weight, the trailer works out admirably. When it comes to very rough going, especially off the road on soft ground, tests made show that the same load can be much more easily and efficiently carried on top of the tractor than in a trailer with a tractor drawing it. There are a number of reasons why this is true, but evidently the main one is the fact that in one case it is only the pay load which is being moved and in the latter case it is the pay load plus a certain dead load equivalent to the weight of the trailer. This conclusion holds good even with a track-laying trailer, for as a rule it is rather heavier in proportion to the load which it carries. The pressure per square inch exerted on the ground is, of course, a great factor in all hauling where the ground itself is soft or irregular, as on very soft ground the vehicle is continually climbing a grade or its equivalent.

The difficulty experienced in towing a long line of trailers behind a truck or tractor is very much simplified if they can be made to track, especially when rounding curves. It is apparent that this is possible only when four-wheel steer is used on the trailers. The tracking of the front wheels of trailers can be controlled by the correct proportioning of the length of the drawbar to the length from the center of the rear axle to the pintle of the truck and the relative length of the drawbar front and rear of the front axle when it is pivoted on the axle of the trailer, the angle of the steering arms controlling the relative angles of the inner and outer wheels.

Caterpillar Track Adapters for Trucks

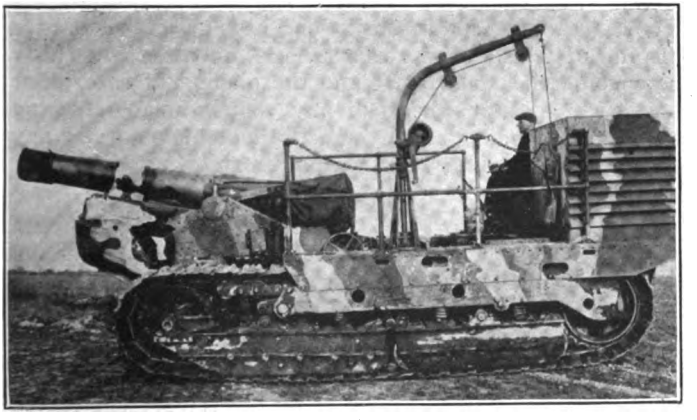
A number of experiments have been made during the last two years in equipping the rear axles of trucks with caterpillar tracks or adapters. These generally consisted of a roller frame having from three to five rollers running on a track which in turn was either geared or driven by chain from the rear axle driving shafts. Experiments were tried on both the four-wheel-drive type

Digitized by Google



75-Mm. Gun on Track-Laying Mount

and the two-wheel-drive trucks. The French had also been using an adapter, chain driven from the rear axle on a number of Saurer trucks. Also, adapters of various sorts of the belt type running on the rubber tires of the truck wheels or with extra wheels added, have been tried. Experiments demonstrated, in the use of these various adapters, that a caterpillar track of this type attached to the rear axle of a truck driving on all four wheels was not at all practical as only a little over 50 per cent of the load was concentrated on the track, the remainder being on the steering wheels, which dug into



8-In. Howitzer on Self-Propelled Caterpillar

Digitized by Google

NAME OF TRACTOR OR TRUCK	SIZE OF ENGINE
Artillery tractor[3] 2½-ton, model 1918	Eight-cylinder, 3⅛-in. bore by 5⅛-in. stroke
Artillery tractor[3] 5-ton, model 1917	Four-cylinder, 4¾-in. bore by 6-in. stroke
Artillery tractor[3] 10-ton, model 1917	Four-cylinder, 6½-in. bore by 7-in. stroke
Artillery tractor[3] 15-ton, model 75-hp. Holt	Four-cylinder, 7½-in. bore by 8-in. stroke
Artillery tractor[3] 20-ton, model 120-hp. Holt	Six-cylinder, 7½-in. bore by 8-in. stroke
Artillery wheeled tractor, model 1918	Four-cylinder, 4¾-in. bore by 5½-in. stroke
Nash 2-ton truck used as tractor	Four-cylinder, 4¼-in. bore by 5½-in. stroke
F.W.D. 3-ton truck used as tractor	Four-cylinder, 4¾-in. bore by 5½-in. stroke

[3]Track-laying type.

the mud and rendered this type of vehicle of little more value in soft ground than the four-wheel type. On account of its limited speed it was not as serviceable for road work. Placing these adapters on two-wheel-drive trucks was a little more successful, but even under these conditions it was difficult to steer in deep mud, and the weight was considerably increased, in the case of the F. W. D. about 1500 lb. In the end it was decided that the placing of tracks on the rear wheels of trucks could only be considered a makeshift and the placing of caterpillar tracks on all four wheels of any vehicle makes steering extremely difficult and, in fact, if the vehicle carries any considerable weight, requires power steering.

Interlocking Differentials

For cargo-carrying vehicles the use of interlocking differentials in the rear axle or, in the case of four-wheel drive, for both front and rear axles, has been of considerable advantage. The difficulty of securing a substantial interlocking differential, it is believed, has been the principal reason why most cargo-carrying vehicles have not been so equipped, although one make on the market, which has been principally used, has held up fairly well. It is

Digitized by Google

DRAWBAR PULL, LB.	WHAT IT HAULS AND NUMBER OF LOADS	HEAVIEST LOAD, LB.
4,000 low gear	75-mm. gun and caisson, 1 load Two 75-mm. caissons, 1 load Six-horse reel and cart, 1 load	4,500
5,000 low gear	155-mm. howitzer, 1 load 9.2-in. howitzer, 3 loads 240-mm. howitzer, 4 loads 4.7-in. gun, 1 load 10-ton trailer in tractor unit, 1 load 4-ton trailer, 1 load	16,230
8,000 low gear 5,200 high gear	155-mm. G. P. F. gun, 1 load 10-ton trailer, 1 load 9.2-in. howitzer, 3 loads	26,400
10,250 low gear 8,900 high gear	Substitute for 20-ton tractor	
15,500 low gear 11,500 high gear	5-in. seacoast gun, 1 load 6-in. seacoast gun, 1 load 8-in. howitzer, 1 load	32,148
9,000 low gear	6-ton tank or 10-ton tractor on 10-ton trailer	24,215
4,000 low gear	75-mm. gun and limber on field gun trailer, 1 load	9,500
4,000 low gear	75-mm. gun and limber on field gun trailer, 1 load	9,500

believed that this mechanism can be very greatly improved.

Considerable argument has arisen with reference to the advisability of using a differential for the transmission on four-wheel-drive trucks and whether this should be of the interlocking type. In the case of a tractor steering all wheels, it is not absolutely necessary to have a differential as the rear wheels theoretically travel the same distance as the front wheels; but when two-wheel steer is used on a four-wheel-drive truck, it is at least advisable to have a differential in the transmission so as to allow for the difference in distance traveled by the front and the rear wheels and in order that traction may be secured through both front and rear axles at the same time. An interlocking differential is considered preferable as otherwise it is necessary to have an emergency lock for the differential. Experiments have shown that a solid shaft can be used even with two-wheel steer, but excessive strains on the driving parts are at times occasioned by this design.

While for military purposes the front wheel on track-laying tractors is not desirable on account of the difficulty in mounting a vertical bank, there is considerable

Digitized by Google

to be said in favor of the front wheel for farm purposes on account of the greater ease in steering.

Troubles Experienced

In the work of the various vehicles used by the Army, both at the front and in the service overseas, it is interesting to note that the troubles experienced have not been of a very serious nature but rather with the small items which have caused continual annoyance, and it is believed that on those small items, although seemingly rather insignificant, considerable engineering work can be done to great advantage.

THE DISCUSSION

JOHN YOUNGER:—Col. Wall refers in his paper to the military controversy on four and two-wheel-drive trucks. There was, I believe, most of the time, a good-natured rivalry between the engineering division of the Motor Transport Corps and that of the Ordnance Department, but I would like to take this opportunity, as one who saw their work very intimately, to congratulate Cols. Moody, Capron and Wall and Major Wahlberg, on their splendid work in initiating and developing the equipment necessary to motorize artillery regiments.

There are two main factors in military mobile equipment, operation and maintenance. Good design will satisfy both, but the operating conditions are frequently very strenuous, and in meeting them the maintenance problem becomes acute. This was the case with the four-wheel-drive trucks. Designed for heavy going on poor country roads, they were set to work in a military atmosphere on no roads at all. Military service demanded that rough terrain should be crossed. The two-wheel-drive trucks were not tried on this, as their limitations were well understood, but the four-wheel-drive trucks were started on the way, with terrific drain on their ultimate life. So far as I can make out from the various comments and reports, the operating division was fairly well satisfied with the four-wheel-drive trucks, but the maintenance division had no use for them. This has led to much unjust condemnation.

As Col. Wall states, the four-wheel-drive truck has advantages over the two-wheel truck within "very narrow limits." I feel that because of these narrow limits the four-wheel-drive truck has not entirely justified itself in the war and that future development of "off-road"

Digitized by Google

equipment must be looked for in the track-laying type. Here, again, while this type of vehicle satisfies operation to a high degree, maintenance is still unsatisfied, and development work must continue along lines that lead to greater reliability, less wear-and-tear and replacement, longer life and freedom from the tendency to "feel at home in the repair shop."

I disagree with Col. Wall in his belief that as a tractor the four-wheel-drive is supreme. As a matter of plain mathematics I cannot see that a 3-ton tractor, weighing because of its strengthened front and rear axles, extra transfer case and universal-joints some 16,000 lb. with body and load, differs in adhesion from a 5-ton truck of the two-wheel-drive type, weighing with body and load 16,000 lb. on the rear axle and 4000 lb. on the front axle. Both have a possible drawbar pull under normal conditions of some 9600 lb. The simplicity of the latter is beyond question. It seems, in view of this, that to add an extra type of vehicle merely for a limited field of tractive work, would complicate the Army program unnecessarily. The Militor four-wheel-drive truck has not, however, been tried out to any extent beyond a half dozen samples, and it might be worth while to suspend further criticism until the Army acquires considerably more experience with it. The last vehicle tested certainly marks a big step forward in four-wheel-drive design. It is hoped, from a technical point of view, that the War Department will see fit to order a number of these for extended trial.

E. R. GREER:—Col. Wall's paper explains a great many interesting points. The military point of view which led to the selection of the various machines for each kind of work is well worth considering in making proper commercial applications. Reliability was of first importance and little attention was given to cost, but when the actual cost of operating motor trucks is figured over long periods of time, it will generally be found that first cost is a small item, and that reliability is what counts most.

It is natural that there has been "considerable controversy, especially in military circles, in regard to the relative advantages of four-wheel-drive and two-wheel-drive types of vehicles." Col. Wall has evidently accepted the popular idea that four-wheel-drive trucks are not as efficient as rear-drive trucks and that they are more expensive to maintain. As a matter of fact, a four-

Digitized by Google

wheel-drive is more economical than a rear drive even on paved city streets. This is because the load is distributed to the four wheels, resulting in less weight and greater tractive efficiency. The tire mileage is practically doubled. If used for the same work as a rear-drive truck, the four-wheel-drive truck will cost no more for upkeep, but because it can go regardless of weather and do "stunts," it is often compared on an unfair basis.

The table of drawbar pulls gives the four-wheel-drive trucks credit for some pretty high drawbar efficiency, 4000-lb. pull at 4 m.p.h., the low-gear speed of an FWD, gives a drawbar horsepower of 42.6. The engine in an FWD is rated 36.1 hp., and can be counted on for 38 hp. at the speed it runs when the truck goes 4 m.p.h. This is 112 per cent efficiency. Actually, 3000 lb. = 32 hp. and is about what can be delivered continuously.

The information regarding carrying or towing loads is very interesting. Some of the trailer builders would like to have us believe it is better to tow a load than to carry one. It is my opinion that for road hauling the best general results can be obtained by the use of a semi-trailer.

Digitized by Google

THE PRINCIPLES OF THE WHEELED FARM TRACTOR

By Edward R Hewitt[1]

GIVEN a light source of power occupying comparatively small space, a tractor can take almost any form and yet do some work. There are certain fundamental particulars, however, which must be heeded if any reasonable degree of engineering efficiency is reached. Their neglect in tractor manufacturing has already caused tremendous financial loss. After a series of laboratory tests on full-size wheels, the following conclusions were reached

(1) The maximum drawbar pull is a definite function of the weight per inch of width. Weights used varied from 10 to 200 lb. per in.; the ratio of maximum possible drawbar pull to total weight on the wheel was constant for that range. This was found to be true whether the ground were wet or dry

(2) On sandy ground the drawbar pull available with a smooth metal wheel is about 30 per cent of the weight on the wheel

(3) On damp, sandy ground the maximum drawbar pull is greater, being about 43 per cent of the weight, and under some conditions even slightly higher

(4) Cleats increase the maximum drawbar pull only insofar as the soil resists shearing; that is, the cleat carries a section of the top soil and slides it against the soil below the edge of the cleat. Experiments indicated that this was practically independent of the depth of the cleat, depending solely on the shearing strength of the soil at the depth of the cleat edge. In some cases the shallower cleat pulled more than the deeper cleat because the roots in the sod were not cut off and advantage was taken of their shearing strength

From this study of wheel work the author passes to the consideration of the power required to propel a tractor, covering his experiments and conclusions under the headings Weight on Wheels, Over-all Efficiency, Fuel Efficiency and Gear Changes and Size of Machines. This is followed by opinions as to future tractor maintenance and durability.

[1]Consulting engineer, International Motor Co., New York City.

Digitized by Google

The hydrocarbon engine has in recent years placed us in possession of a light source of power for the purposes of farm traction. It is easily controlled and operated by one man. This has given the farm tractor problem quite a different position from that which it occupied when steam was the only method of propulsion. Although it was possible to make a one-man steam machine, this was not usually done, and the steam plant always had so many disadvantages in starting, use of water, leaking connections, etc., that its extended use was not to be expected.

Given a light source of power occupying comparatively small space, a tractor can take almost any form and yet do some work. While there is certainly vast latitude in design, and many different forms accomplish the purpose equally well, the fundamental principles governing the problem lay down certain postulates which must be followed if we are to reach any reasonable degree of engineering efficiency. It is to the study of these principles that I wish to draw attention, as their neglect has caused tremendous financial losses to both the manufacturers and the public. I will take up the problems, beginning, as we may say, from the ground and giving the results I have reached from my personal observation.

Friction of Wheel Upon Ground

A series of laboratory tests on full-sized wheels, which checked very well with work on the machine in the open, resulted in the following conclusions:

(1) The maximum drawbar pull is a definite function of the weight per inch of width. Weights used varied from 10 to 200 lb. per in.; the ratio of maximum possible drawbar pull to total weight on the wheel was constant for that range. This was found to be true whether the ground were wet or dry

(2) On sandy ground the drawbar pull available with a smooth metal wheel is about 30 per cent of the weight on the wheel

(3) On damp, sandy ground the maximum drawbar pull is greater, being about 43 per cent of the weight, and under some conditions even slightly higher

(4) Cleats increase the maximum drawbar pull only insofar as the soil resists shearing; that is, the cleat carries a section of the top soil and slides it against the soil below the edge of the cleat. Experiments indicated that this was practically independent of the depth of the cleat, depending solely

Digitized by Google

on the shearing strength of the soil at the depth of the cleat edge. In some cases the shallower cleat pulled more than the deeper cleat because the roots in the sod were not cut off and advantage was taken of their shearing strength

In some cases subsoil may be more tenacious than the top, but this is unusual. It might be supposed that when the top is sheared from the subsoil, the soil at the *back of the wheel* would support it if the section were deep, to a greater extent than if it were shallow. This does not appear to be the case because of the lifting action of the back of the wheel which tends to eliminate the support. This is particularly noticeable on hills when the wheel is stressed to the limit. It was found that a cleat inclined forward at an angle would improve this condition somewhat. In going uphill the cleat enters the soil almost horizontally, acting like a step and tending to lift the weight off the wheel. On leaving, the cleat stands almost vertical and causes less friction and loss of power. An inclination of about 30 deg. was found to be the most satisfactory on a 6-ft. wheel. This arrangement tends to self-clean to a great extent. Setting the cleats at an angle of 30 deg. to the axis of the wheel also helps this cleaning effect by a slipping action. The shearing strength of the soils I tested appeared to vary from 5 lb. per in. of width in dry molding sand to 75 lb. in loam or sod. No doubt, tough sod or gumbo may prove even stronger than this.

From these facts it becomes evident that weight is the only means of obtaining a tractive effort of 40 per cent of the weight of the machine under bad conditions in dry ground or sand, as cleats will be of little use. Wheels 72 in. wide would give an added pull due to the use of cleats of only 360 lb. for loose ground. Weight is therefore practically the sole reliance for traction in sand or very dry loose ground. In sod or damp ground 72-in. wheels would ordinarily give 4000 to 5000 lb. pull from the cleats alone, and the light machine with only sufficient weight to hold the cleats down would show good results.

Power Required to Propel the Tractor

Certain observations in operating a tractor led me to believe that the rolling losses were greater than I had anticipated, and I began a study to determine the laws governing the subject.

I took a watering cart having 46-in. wheels with 8-

Digitized by Google

in. flat tires, and removed the tank, leaving only the stripped chassis. This was towed by a motor truck over several kinds of ground, and the drawbar pull was measured by spring scales. After this I replaced the body and filled it successively with various amounts of water to increase the load per inch of width on the wheels. Four types of ground surface were tested: (*a*) hard macadam road; (*b*) dry short clover; (*c*) sod long grass (gravelly loam); (*d*) dry plowed land, such as would ordinarily be harrowed, plowed 24 hr. previously.

The drawbar pull was found to increase rapidly with the weight per inch of width on a regular curve on all but the hard macadam road, where the increase was only slight. This was to be expected, as the increase in pull is due to the work done in crushing the ground surface, or, in effect, continually pulling the wheel uphill. The limits selected for the tests were those under which a tractor can be built. The curve, Fig. 1, shows the ratio of the drawbar pull required for propulsion to weight plotted against wheel width in inches. The speed used was about 2 miles per hr. I could notice no marked difference in the pull from 1 to 3 miles. On some previous experiments I had observed that the rolling friction of wheels of various sizes varies inversely as their di-

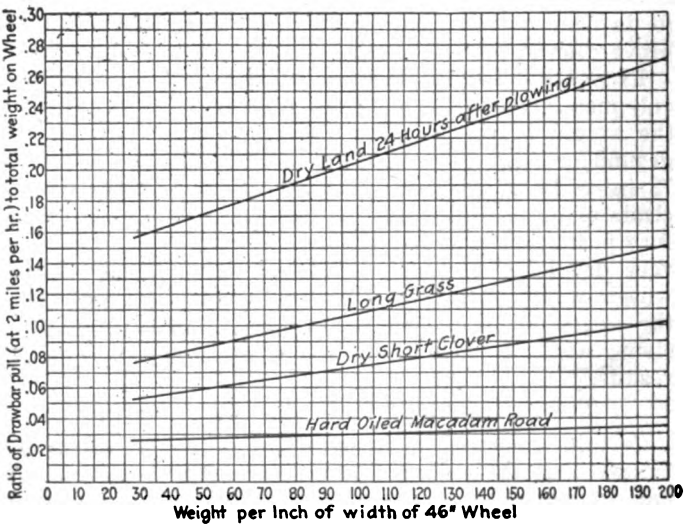


FIG. 1—RELATION BETWEEN WEIGHT PER INCH OF WHEEL WIDTH AND THE RATIO OF DRAWBAR PULL TO WEIGHT

Digitized by Google

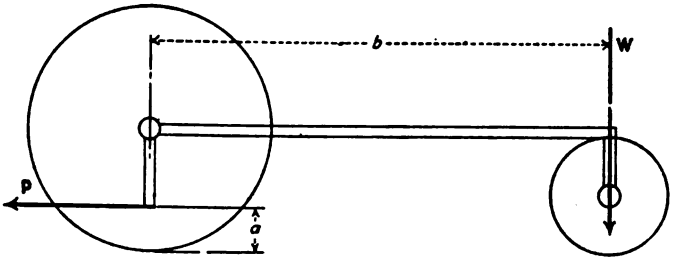


FIG. 2—DIAGRAM OF THE RELATION BETWEEN THE MAXIMUM DRAWBAR PULL DEVELOPED BY A TRACTOR AND THE WEIGHT ON THE WHEELS

ameter and I believe that this fact can be used with the chart as a basis for design. It would certainly be valuable to have these observations extended further to furnish a more certain basis for calculation. I have yet to see any precise data on this subject.

The value of these facts is obvious. If a tractor has too great weight per inch of width of wheel and gets on soft ground, as it must do in harrowing, etc., the power consumed in rolling friction becomes a large percentage of the total developed and the drawbar pull is proportionately decreased. There is every advantage in increasing the surface and reducing the weight. Tractors with a weight of over 200 lb. per in. of width of wheels that are even 6 ft. in diameter become very inefficient on soft ground. It is here that the "caterpillar" shows to best advantage, and if it were not for its complication and high maintenance cost, it might prove somewhat better than the wheel for many purposes. When properly proportioned, however, the wheeled machine can be made to give a very high efficiency, as I will show later on, and since wheels can be made to last the life of the machine without expense or renewal, their design is worthy of very careful study.

WEIGHT ON WHEELS

Considering a four-wheel machine, with the rear wheels as drivers, it is evident that no matter what form of mechanism is used to apply the power to the wheels, the maximum drawbar pull multiplied by its lever arm ($P \times a$) cannot exceed the weight on the front wheels multiplied by a lever arm equal to the distance from the center of the front to the center of the rear wheel ($W \times b$), Fig. 2. The maximum pull which can be applied will be only that required to lift the front weight off the ground.

Digitized by Google

If the machine is on a hill, this weight will be reduced as the cosine of the grade angle. In other words, when we apply power to the rear wheels we are in effect transferring part of the weight of the machine from the front to the rear wheels.

From the preceding curves it is easily seen that the increase in the weight on the rear wheels would increase the weight per inch, and so increase the rolling friction. In the first machine I designed this was very marked, as I increased the weight on the rear wheels 3500 lb. by applying full engine power, and increased the rolling friction from 20 to 25 per cent on plowed ground. The machine, therefore, did not show the drawbar pull it should from power developed by the engine. It took me several months to find the cause of the losses, and I was not absolutely certain until I had actually brake-tested the machine on the rear wheels under full power and found that the mechanical losses from the engine to the ground were only 16 per cent and did not increase materially with the lower gear ratios or increased power. Besides these serious frictional losses, very few machines in this country are proportioned in such a way that the full engine power can be applied on the low gear on any reasonable hill and not raise the front of the tractor off the ground. This interferes with the steering, and in many cases the tractor will turn over if the operator does not shut off the power. This is dangerous, and the full power of the tractor is not available. The utmost care should be exercised in having the weight on the front exactly right for the work it is desired to perform, and any failure here is inexcusable.

If we consider a machine driving from the front wheels, the reverse is true, and the application of power decreases the weight on the drivers and reduces the possible drawbar pull which can be delivered with a given weight of tractor. This type is therefore inefficient and will eventually be abandoned. The rear-drive type can be proportioned so that nearly all the weight of the front can be carried by the rear wheels when the full engine power is applied, leaving only enough weight for proper steering. This form will then develop the greatest possible pull for a given total weight.

Overall Efficiency

By using anti-friction bearings, good lubrication and cut gears of good design, it is possible to reduce the

Digitized by Google

frictional losses from the engine to the rim of the rear wheels to less than 16 per cent of the total power developed. I found on brake test of one machine that the losses with a gear reduction of 172:1 on third speed were not materially greater than the losses at 52:1 on the direct drive, where they proved to be 12.5 per cent. This is understood when we consider that we are only interposing two additional pairs of gears, the gears being well oiled and of ample size. As these gears are running in oil when the tractor is operating on the direct drive, they have under these conditions the friction of the oil in the box, which is very considerable, gearbox-oil friction with heavy oil being about 3 hp., and about ½ hp. with light oil. To the mechanical losses must be added the rolling friction on the ground. As seen above, this may vary from 8 to 20 per cent with properly proportioned wheels.

In testing the engine on the brake I used a vacuum gage on the inlet pipe and noted the suction at various loads at the governed speed. When the engine was put on the tractor again I used this gage, which gave me the actual horsepower of the engine within a very small error, as the engine in both cases was operating at the same governed speed. A speedometer was employed that gave the feet of advance per minute of the tractor on each gear. A spring dynamometer was applied to the drawbar, giving the reading in pounds. It was a simple matter to multiply the pounds pull by the feet of advance per minute, get the delivered horsepower and compare it with the actual engine power. It was found that on good sod with short grass the efficiency of the machine was about 75 per cent, i.e., the drawbar horsepower divided by the engine horsepower was 0.75. On plowed ground, harrowing or cross plowing, it was about 65 per cent, and never fell below that figure. When we consider the low efficiency of touring cars and trucks this seems a very satisfactory result on soft ground, and one which the engineer would scarcely expect to exceed.

Fuel Efficiency and Gear Changes

The internal-combustion engine of conventional type has one serious drawback; if it is overloaded it stops at once, unless it is operating at a speed such that it is beyond its maximum torque point, and slowing down allows the torque to increase. In this case the normal load of the engine can be slightly increased at the expense of the speed. These being operating conditions, it

Digitized by Google

is evident that on a tractor the engine must be regularly operated below full load, or a specially hard pull on the plows or a slight hill will cause it to stop or necessitate a change of gears. It is, therefore, the usual practice to gear tractors in such a way that the engine is operated only at a small percentage of full load, say 40 or 50 per cent. This provides the safety factor for overloads and for defective oiling and cooling, as the overloads may prove to be of short duration. The curves, Fig. 3, taken as an average of tests made during several years in my own laboratory of a number of good engines, show the best fuel economy at various percentages of full load, all tests being made at the constant speed of 1000 r.p.m. The lower curve shows the best fuel economy I have yet obtained when operating conditions were at their best. The curve marked 1 may be taken to represent ordinary practice in commercial tractors. As we cannot operate continuously at full load and best economy, it is interesting to see just how far below this point we can go before the increase in fuel becomes very marked. It will be noted that we should not go below 60 per cent on an ordinary engine, while on the best ones under good conditions a fuel economy of 0.66 lb. per hp.-hr. can be obtained at 50 per cent load. Tractor engines should not be used below this point over long periods. Another point to be noted is the absolute necessity of having the engine oiled and cooled so that it can run all the time at 50 per cent to full load, if we are to secure good fuel economy. A tractor, however, should work at certain specified speeds for best results on the tools used, and the pull of these tools will vary as much as 100 per cent in the same field, not to mention hills and variations of rolling resistance.

How, then, are we to get good fuel economy with two changes of gears? In my original machine I had three speeds; the high speed was reserved for road use and could not be used in the field, leaving only two speeds for actual work. I have been obliged to adopt four speeds so as to have three available speeds for field work. These are respectively 1, 2 and 3 miles per hr. at 1000 revolutions of the engine. The latter is governed to 1200 r.p.m. In this way it can be used under the proper load conditions all the time for best economy.

I use a suction gage on the inlet pipe as an indicator of the engine load, and have this marked so that the driver knows that it should not read over 8 in. of mercury suc-

Digitized by Google

tion, which is 50 per cent load. This point was selected as the minimum load under which the engine will operate economically. If the suction rises above this point, the driver should shift to a higher gear and load up the engine further. This is just the opposite of touring car practice, where we shift gears because the engine is overloaded and needs relief. On the tractor, the heavier the load, the better the fuel economy will be, and the better the financial result, provided the engine is able to

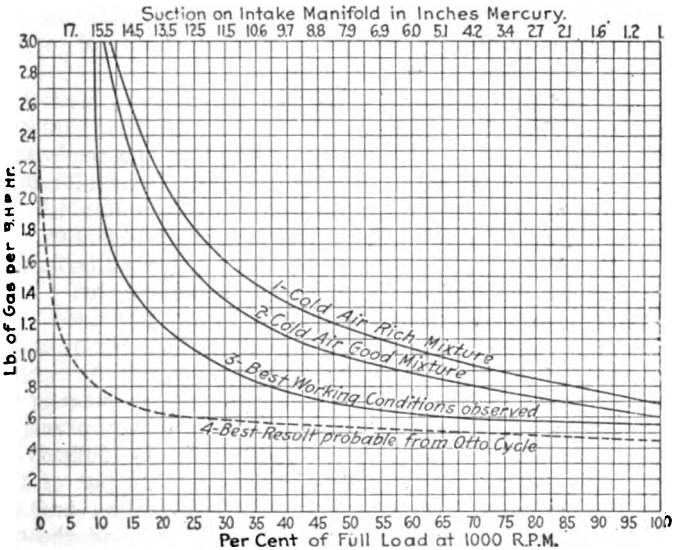


FIG. 3—FUEL ECONOMY AT VARIOUS PERCENTAGES OF LOAD AVERAGED FROM A NUMBER OF TESTS

stand this load. We must build engines capable of holding their full power, and a cooling system that will keep them within reasonable ranges of temperature under all conditions, if we are to secure economical operation.

SIZE OF MACHINE

The size of the machine is a subject of supreme importance, and I am in the unfortunate position of being obliged to differ with the general opinion that the small tractor is the future economical unit.

The expense of operating may be divided into the three

Digitized by Google

main headings of operator's wages, fuel and oil, and maintenance charges.

The driver on the small machine is paid as much as on the large. The maintenance charges for actual repairs on the larger machine, if properly constructed, are not materially greater than on the small machine. The only difference here will be in the interest and depreciation items. The cost of fuel and oil will prove to be the main difference in expense. This, however, is much lower per acre on the large unit than on the small; therefore, the operating expense per acre on the large machine will be less than on the small machine, primarily because the driver's wages will prove to be at least one-third of the whole cost.

The evident answer to the question of how large the machine should be made is as large as one man can operate easily and as large as can be run on the roads and pass through gateways and over bridges. I consider that a width of 9 ft. overall on the wheels is the outside limit in practice, and a total operating weight of 14,000 to 16,000 lb. With this weight eight plows can readily be operated, plowing at the rate of 2.8 acres per hr. This would seem to be about the practical limit for a one-man machine. The two-plow machine, on the same basis, would do 0.7 acre per hr. These figures are for the regular progress of the machine over the ground, making no allowance for delays and turns. In factory practice, with automatic machinery, it is found very difficult to get over 80 per cent of the best possible output of the machinery, and this is true when all the oiling and repairing are done outside of working hours and the operators have skilled superintendence.

How much lower ought we to expect the percentage of time in operation to be on a tractor subject to delays for oiling, filling and adjustments, not only of the machine, but of the plows and tools, stopping for corners and turns, shifting gears, etc.? An output of 60 per cent of the theoretical would be very good indeed, and I fear that it often proves to be very much lower. If we take 50 per cent of 7 acres for a day's work we get 3½ acres on an average, and this is more than is usually obtained over any long period with the two-plow machine.

At the present time there are no eight-bottom tractor plows on the market which can be worked satisfactorily from the tractor by one man. I have made a set for my machine which works fairly well, but it will be

Digitized by Google

some years before these devices can be perfected. Four-bottom plows are now to be had which with a few changes can be made to work fairly well from the tractor. It is probable that at the present time, taking into consideration all the facts of economy, first cost and ease of operation, the four-plow machine is the best suited to build. This is especially true when we consider that it is possible to design a four-plow machine with substantially no side-draft and operated with the tractor wheels of ample size running on the unplowed ground.

I have just had the opportunity of getting figures from three of the best standard makes of machines, working in Orange County, New York, on difficult land. They were operated for a whole season by a township committee. The machines have averaged about an acre a day each during the season. The same money invested in horses would have done more and a larger variety of work. The cost per acre has been much greater than with horses, and the three machines all need rebuilding at considerable expense. With a capacity of 20 to 30 acres a day, we have a good chance to get 10 or 15 acres regularly. In my view, it is not the first cost of the whole outfit that will be the deciding factor, but the investment per acre worked per year. If the large and more expensive machine will do the work more cheaply, and at the same time show a lower investment per acre, it will be the one to survive in the long run. Small machines are advertised to pull mowing machines, reapers, cultivators, etc. It seems rather a step backward to be pulling these machines by a means costing at the lowest estimate from $5 to $8 a day to operate, when we can do it with horses at not over $4 to $4.50; or to be running a thresher and silo cutter with a machine costing between $900 to $1,500, when we can do the same work with a stationary engine costing between $200 and $300; while the tractor could be plowing and doing expensive work on the farm. My view is that the small tractor is rarely needed at all for the small farm. On any farm up to 100 acres the work can be done with horses more cheaply and better, especially if the farmer uses the right crop rotation and carries enough live stock. The small tractor would only be a source of expense, as he would certainly have to keep horses as well. The tractor should have at least 200 acres to cover a year, and better still, 500 or 1000. On this large output a skilled man can be employed and the machine properly worked. The tractor and farm

Digitized by Google

tools that the farmer will have available for some years to come are certain to be the kind of machinery that should not be placed in the hands of the untrained.

Conclusion

In closing, I would like to add a word as to what can be expected in the future as to the maintenance and durability of good tractors.

A motor-truck designing experience of twelve years has taught me that a well-made, properly designed gear-box and clutch will last from five to ten years with no repairs, and I see no reason why we should not expect even better results on tractors if we proportion the loads properly, especially as the tractor will not operate more than 120 days a year. The wheels on my machine show no wear after two years' work, and I am sure they will last the life of the machine, with the possible renewal of cleats every four or five years. The frame, riveting and steering-gear can be made absolutely durable. The two places in which we will have excessive wear are on the final drive to the rear wheels and on the engine. The main drive to the wheels is not durable on any machines I have seen. On my own it has lasted two years and requires renewal. It will be replaced with a drive of better proportion and materials, and better protected from dirt; I hope to get four years out of it at least. This can, no doubt, be further improved. On the engine the main source of wear is the dust in the cylinders. Even with a fine muslin dust filter 8 sq. ft. in area the pistons and rings were badly worn in 100 days' running. A perfect air cleaner is an absolute necessity for tractors. Those I have seen advertised thus far are all of types which will not really remove the finest particles of dust, which do the actual damage to the engine, and they cannot eliminate the trouble. If we succeed in protecting the engine from dirt, there is no reason why we cannot get ten years' service out of it, with a regular overhaul every year or two. I know of motor-truck engines in operation today which have been in constant use for over ten years, and I firmly believe we shall make a tractor in the near future with a very low maintenance cost and a very low operating cost per acre. I believe we may hope to plow for about 60 cents per acre, on good land, this including all charges, as against $3 to $4.50 with horses. If this is accomplished, the tractor engineer will have done his bit toward solving the food problem.

Digitized by Google

THE DISCUSSION

D. L. ARNOLD:—Mr. Hewitt has developed this formula for weight on wheels:

The maximum drawbar pull multiplied by its lever arm from the ground to the center of the drawbar cannot exceed the weight on the front end multiplied by its lever arm equal to a distance from the center of the front wheels to the center of the rear wheels; or in other words:

$$P \times a = W \times b \text{ wherein}$$

P = the maximum drawbar pull in pounds
a = the distance from the ground to the center of the drawbar
W = the weight on the front wheels
b = the wheelbase

These factors are not the only ones entering into the reasons why a tractor will tip over. If the powerplant of the tractor has insufficient torque, regardless of the drawbar pull or the weight on the front end, it will be impossible to have a tractor tip over or pull its maximum drawbar pull. Therefore, the maximum torque of the engine and gear reduction on the tractor is as great a factor as those heretofore mentioned, if not greater. Taking these factors into consideration, the formula should be for the tractor equilibrium:

Gear ratio multiplied by engine torque in pounds-inches equals the wheelbase in inches multiplied by the weight of the front end in pounds.

The cosine of the angle of inclination the tractor makes with a horizontal must also equal the maximum drawbar pull in pounds multiplied by the height of the drawbar from the ground; or in other words, the general formula is:

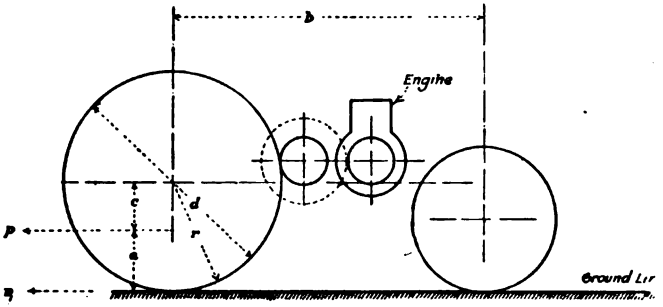
$$GT = bW \cos V = pa$$

The derivation of this formula is shown below.
The tractor front end is unstable when

$$GT > bW + pc \text{ or when}$$
$$pa > bW \text{ or}$$
$$GT > pa$$

a = Height of drawbar center from ground line in inches
b = Length of tractor wheelbase in inches
c = Vertical distance from drawbar center to rear axle in inches

Digitized by Google



d = Diameter of rear wheel in inches
G = Gear ratio or relation between engine and rear wheel speeds
G_r = Gear ratio reverse
G_1 = Gear ratio first speed
G_2 = Gear ratio second speed
G_3 = Gear ratio third speed
G_4 = Gear ratio fourth speed
M = Engine speed in revolutions per minute
p = Pressure at drawbar in pounds or drawbar pull in pounds
p_1 = Pressure between driving-wheel and ground in pounds
T = Engine torque in pounds-inches
V = Angle above horizontal at which tractor stands
W = Actual weight of front end

NOTE:—The actual weight will vary with the angle at which the tractor is used, being greatest when the tractor is in a level position and decreasing as the angle increases. Neglecting changes in the center of gravity this weight varies as the cosine of the angle; hence

W should be written $W\cos V$

r = Rear wheel radius
S = Rear wheel speed in revolutions per minute
F = Speed in feet per minute

When equilibrium of the tractor relative to ground movements is established

$$p = p_1$$
$$p_1 r = GT$$
$$pr = GT$$

For forward movements of the tractor GT must be greater than $p_1 r$.

Digitized by Google

The effect of drawbar pull on the front end is given below.

pc	= Pounds-inches torque on the rear axle due to the drawbar pull p
pc/b	= Additional weight effect added to the front end due to the drawbar pull p
bW	= Additional weight effect added at the rear axle due to the weight of the front end only with tractor level
$bW\cos V$	= Pound-inches torque effect at the rear axle due to the weight of the front end when inclined up from the horizontal at the angle V ($W\cos V$ will probably not be exactly correct and the tractor will have to be weighed at the angle V for the correct figures due to the changing the center of gravity)

Where sufficient engine torque is available to equal the effective pounds-inches of torque tending to hold the front end down the tractor front end will be in equilibrium. Equilibrium of the front end is established when

$$GT = p_1r = pc + bW\cos V$$
$$p_1r = pc + bW \quad \text{or}$$
$$bW = p_1r - pc \quad \text{as}$$
$$p = p_1bW = p\ (r - c)$$

Substituting a, which is the equivalent of $r - c$, we have

$$bW = p\ (c + a - c) \quad \text{or}$$
$$bW = pa = GT \text{ for equilibrium}$$

Therefore the tractor front end will leave the ground and tip over backward when

$$bW < pa$$

The drawbar pull at equilibrium can be expressed by the equation

$$p = bW \div a$$

The rate of travel is expressed in either miles per hour or feet per minute. The speed in feet per minute equals the speed in miles per hour multiplied by 5280 and divided by 60, or 88 times the rate of travel in miles per hour. The speed in miles per hour is equal to the rate of travel in feet per minute divided by 88 or multiplied by its reciprocal 0.0113636.

The gear ratio is the relation of the engine speed in

Digitized by Google

revolutions per minute to the rear-wheel speed in revolutions per minute.

$$G = \frac{M}{S}$$

$$S = \frac{F}{\frac{d}{12}} = \frac{F}{0.2618 - d}$$

$$G = M \div \frac{F}{0.2618 - d} \text{ or}$$

$$G = \frac{M\,(0.2618 - d)}{F}$$

The source of motive power in the tractor is that force delivered at the end of the revolving shaft of the power-plant and is measured in pounds-inches torque or pounds-feet torque. The pounds-inches of torque at the rear axle then equals GT, neglecting efficiency of transmission.

Summarizing the conditions for equilibrium, we have

$$GT = bW = pa$$

$$G = \frac{bW}{T} = \frac{pa}{T}$$

$$T = \frac{bW}{G} = \frac{pa}{G}$$

$$b = \frac{GT}{W} = \frac{pa}{W}$$

$$p = \frac{GT}{a} = \frac{bW}{a}$$

$$a = \frac{GT}{p} = \frac{bW}{p}$$

The values for W will change approximately as the cosine of the angle of inclination the tractor makes with the ground, the best values being taken from the actual weight at various angular positions.

The general formula for equilibrium may thus be written

$$GT = bW\cos V = pa$$

MR. HEWITT:—Mr. Arnold has carried out my idea in a very complete manner and he must be commended for finishing the theory. I did not attempt in my paper to make a complete working formula but only called attention to the fact of the front end revolving about the axis of the rear wheel if the power applied exceeded the

Digitized by Google

weight of the front end as increased by the leverage. It seemed to me that any competent engineer could make his own calculation if the matter were brought to his attention.

E. R. GREER:—In pointing out the effect of lugs or cleats on traction wheels, Mr. Hewitt has overlooked the advantage that can be obtained from spiral extension cleats when they are properly spaced. This type of cleat not only cleans itself, but it compresses the soil without shearing it, and, due to the slight slipping of the wheels, there is a side-thrust on the ground not actually rolled over by the wheels. I do not think that the shearing strength of the soil times the width of the traction wheel rim, is the limit of possible tractive effort from cleats. Before condemning tractors with front-wheel drive, it might be well to consider that about 80 per cent of the work done by tractors is on more or less hilly ground, where this type of drive has a tremendous advantage. As the weight on the rear or steering wheels becomes greater when going up hill, the control of the tractor is made more positive, so that this difficult condition is easily met. This type has another great advantage in that it greatly reduces the drift of the implement when used on side hills; it also makes it possible to build the tractor so that over 85 per cent of its weight is normally on its drive wheels. It can never rear up and kill the operator. The percentage of load for a tractor engine is usually nearer 90 per cent than 50. In deciding on the proper size of tractor it is hardly right to consider plowing only. It makes a great difference whether the tractor is to be used on a "small grain" farm or where corn is the principal crop. Plowing in any case is less than 50 per cent of the work to be done.

DANIEL ROESCH:—Referring to the chart showing the relationship between fuel consumption per brake horsepower per hour, per cent of full load at 1000 r.p.m., and the suction on intake manifold in inches of mercury, the curve of the best result probable from the Otto cycle intercepts the fuel consumption ordinate at 2.3 lb. of gas per b.hp. per hr., with the engine at zero load. This is a condition that can never be realized in an engine having friction, since the figure is obtained by dividing the pounds of gasoline necessary to operate the engine by the load in brake horsepower. The quotient is infinity and the curve should show asymptotic to the ordinate with somewhat the same characteristics as the other curves at

Digitized by Google

light loads. The relationship between the upper horizontal scale of intake manifold depression, and the lower horizontal scale of per cent of full load is worthy of further inspection than that given by the author. It is to be noted that the upper scale is not proportional. Plotting these two variables on coordinate paper shows results consistent both in themselves and as compared with numerous parallel tests conducted in the laboratories of Armour Institute of Technology. The effect of the particular compression used in an engine will, however, greatly modify the upper scale. This upper scale as shown indicates a 1-in. carbureter resistance at wide-open throttle while operating at 1000 r.p.m. and by exterpolation, 18-in. manifold depression when the engine is operating at 1000 r.p.m. without external load. Factors of increased compression, maximum and decreased frictional losses, mechanical and fluid, may increase this latter figure to 20 in. of mercury depression or more. These same factors may decrease the right-hand scale limit of intake manifold depression from 1 in. of mercury to 0.5 in. less. Tests made on the same engine at 1000 and 2000 r.p.m. from wide-open throttle to no load show practically no variation in the relationship between intake manifold suction and per cent of full load. In connection with the author's discussion of the curves shown on this chart, it would appear to have been desirable to note the feature of inherent lower compression occurring with increasing manifold depressions, and producing the high fuel consumption at the lighter loads. Along these lines he discusses the relative frictional losses in a tractor and an automobile, but omits to bring out the relative loads on the engine and power transmitting parts of the two machines. Observations by the writer, extending over a period of several years, show from 13 to 16 in. of manifold depression in an engine driving a passenger car at say 20 miles per hr. Taking the chart in this paper, we find this to correspond to from 22.5 to 12.5 per cent of full load. The car frictional loss in per cent will be higher under these conditions than when the case of the tractor is taken and its engine operating at 60 per cent or more of full load, at the particular operating speed. The frictional losses, actual or in per cent, must be taken under parallel or all load conditions for comparison.

The method of estimating the approximate horsepower of the engine in a tractor by observation of known intake manifold depressions obtained from tests, appears

Digitized by Google

commendable where extreme accuracy is not desired. There is an opportunity, however, for introducing large errors when dealing with differences of power determined under variations of mixture, spark advance, cooling water, barometric pressure and air temperature and humidity.

The further reference of the author to intake manifold suctions are certainly worthy of extended study, and undoubtedly will serve to depict operating and test conditions more clearly and correlate them.

H. L. HORNING:—Our experience indicates that tractor engines should be so designed as to have maximum torque about 30 per cent below governed speed, and a governed speed slightly above the speed of maximum economy. Tractor engines in our experience do not work at half load, but at such a load as to be beyond the limit of the governor; hence the advantage of a rising torque curve at speeds decreasing from governed speed. The average speed of tractors is governed not by the governor or design, but by the maximum speed at which the farmer cares to ride, which is almost always determined by the depth of the plows. Hence the engine is working at overload most of the time, as the average shop man would say. A distinction which tractor men should learn with regard to engines before they can get very far is that an overload on a tractor engine must not mean a load which injures the engine through continuous performance. There is no load which can possibly injure any first-class tractor engine. The term overload as used can mean only one thing; namely, that the horsepower at the drawbar is not sufficient to maintain drawbar demands and governed speed. The thing to suffer must be the speed. It does little harm for the speed to drop. The torque, hence drawbar, must persist and so must the engine. Speed of the tractor is the only factor which can vary without serious consequences at the maximum demands of the tractor. As it actually happens, the farmer drops the plow as deeply as possible until the engine slows down to such a point that he simply cannot tolerate the speed. If the engine slows down below its speed of maximum torque before the farmer gets restive, the engine dies. The farmer usually becomes impatient and lifts the plow, and the engine speeds up to a rate which balances with the torque demand of lesser plow depth. And so the law of supply and demand works out through the plowing season with the same flexibility as it does in the broader eco-

Digitized by Google

nomic fields. The farmer demands all he dares from the engine. The engine gives all it can. If the farmer demands too much, the engine supplies less, which is the equivalent of the price of a commodity going up. If the farmer eases off on the demand, the engine gives more, which means that price for the commodity, traction, decreases. Those who have developed a governor through years of experience know that its wear is very moderate in plowing work, but it wears out rapidly in belt work, a strong proof of the statement of average use in which the governor is wide-open and the engine operating by itself in the zone of stability.

The price of fuel must be out of all proportion to current commodity prices to make fuel economy of primary and absorbing interest to farmers. Our experience is that farmers buy kerosene tractors but burn gasoline. The kerosene attachments up to this time are mostly safeguards against exorbitant prices of gasoline.

Generally speaking, tractors must give larger returns than they have in the past. This particularly applies to small tractors of the two-plow type, which operate under handicaps in competition with larger sizes.

There is little to be pessimistic over, as we have not yet manufactured 7 per cent of the tractors necessary to saturate the market, and our experience is necessarily slight and our ignorance profound.

R. B. SHOOP:—The shape of the cleats has a definite bearing on the effectiveness of the field resistance. If a cleat or lug disturbs the surface of the soil when entering the ground, the effective face of the resisting surface has been reduced, with a loss of footage, especially if the soil is light and the cohesiveness of the ground is almost reached. My observation has been that the movement of the soil under the backward pressure is almost the form of a right-angle triangle with the hypotenuse as the line of breaking soil. If the cleat has an involute curve the ingoing and outcoming movements are vertical and do not break up the soil, but rather compress it, giving more resistance to the action of the lug.

There have been pro and con arguments relative to the size of the tractor. Some years ago the president of one of the largest tractor companies started considerable discussion when he pronounced the small tractor an economic impossibility. He neglected to take into consideration the tendency of the modern farms to use power, when possible, and would not consider that the large tractor

Digitized by Google

did not yield suitable returns on the small farm, either as an individual or community purchase. The greatly increased production of 1918 was due in no small way to the two, three and four-plow tractor; in fact, without the small one-man machine, operated by the boy or elderly man, it would have been impossible.

I have observed that it is seldom necessary to put any devices on a tractor to induce the farmer to work his machine at nearly maximum capacity; on the contrary, tractor engineers have been trying to find some way to prevent the abuse of overloading. The average farmer, if he considers that his tractor can do more work, will unhesitatingly put more implements in service. A tractor in the hands of a farmer works at approximately 90 per cent of its capacity from 70 to 80 per cent of the time.

A three or four-speed transmission would sometimes be of advantage, but when the extra mechanism and extra weight, together with extra cost, are considered, it is of doubtful economic value, especially when 1 lb. extra weight means 1 gal. of fuel in the life of the machine.

A. F. MOYER:—I undertook research on the performance of wheels in soft soil about 2½ yr. ago, but have been able to experiment only on rolling resistance, although the intention of experimenting on tractive properties of drive-wheels was kept continually in mind. This work is just about to be renewed on a large scale after interruption by special war training of the U. S. Army and Navy in our laboratory. If Mr. Hewitt wishes further "precise data on this subject," the original record books will be gladly opened to him at any time he wishes to call at the Experimental Engineering Laboratory, University of Minnesota. His statements regarding the friction of drive-wheels on the ground is of much interest, but may not be fully accepted by all. It would seem that the adhesion obtained by a series of narrow spade or cone shaped lugs might be different from that resulting from long cleats extending entirely across the tire.

The power required to propel the tractor as determined by the author is based on interesting data which will permit the bearing values of different soils to be numerically determined from formulas. The author does not state whether the water cart used in his experiments was of two or four wheel construction, and, if of the latter, whether the rear wheels tracked the front ones. The

Digitized by Google

rear wheels of a tractor are usually of a broader tire than the front pair, and do not always run in the same track. The statement of the variation of resistance with different wheel diameters would be in general correct if it were amended to read, "varies inversely *with* the diameter" and not "*as* the diameter." Such a mathematical relation is only vaguely approximate. The amended clause signifies that as the diameter increases resistance decreases, but the relation involves at least the square of the diameter based on theoretical grounds, and experiment has shown that a still higher exponent ought to be used, as the soil will bear up more per cubic inch displaced under a wheel of large diameter than under one of small diameter. The author states that he notes no marked difference in the resistance to rolling between 1 and 3 miles per hr. I have repeatedly obtained differences of 15 per cent and often more between these limits, resistance increasing with velocity.

The author's method of measuring the power input in his tractor is of considrable interest and at least approximate. Without research on the method, the possible error cannot be prognosticated. This is one of the many instances in which approximate data are better than none.

The discussion of torque load on the engine with relation to fuel economy is true when the engine is turning at its best speed, but shifting to a higher gear when the drawbar load becomes light will usually be accompanied either by a speed too high for the implement or an engine speed below that of the governor, which is impractical, and probably with inferior fuel economy.

To one who knows the history of the large gas tractor as pioneered in Minneapolis 10 yr. ago, the consideration of tractor size will exclude the very large unit. Without question the two-plow unit is too small for economy. From three to six-plow sizes, in my judgment, have the best possibilities, with a slight preference for the four-plow machine.

R. W. LOHMAN:—It is indeed refreshing to have a manufacturer of tractors come right out in the open and say that if, for instance, a maximum theoretical capacity of 100 acres per day is provided in tractor equipment we may possibly find at the end of a week that the average acreage handled has been as much as 50 acres per day. If other tractor makers had been equally frank, or as

Digitized by Google

well informed, in the past, power farming might be more favorably regarded by the average farmer than it is today. The usual method of considering the expense of any farming operation, say plowing for example, as the simple cost of the crew, fuel and supplies, divided by the maximum number of acres which a tractor can plow *while actually in motion,* is wholly erroneous and misleading, omitting, as it does, all indirect production labor, all indirect supplies and material and all fixed charges. As the result of 8 yr. detailed observation and experience with various tractors, 50 to 60 per cent of the actual available plowing hours is all that the average farmer, with ordinary mechanical ability, can be expected to get out of his equipment.

In determining the capacity of certain equipment required for the cultivation of 24,000 acres this coming year, we found, for example, that a 120-hp. tractor should, theoretically, plow 62.5 acres every 10 hr., or 125 acres per night and day shift of 20 hr. Falling back upon our records, however, we found that only 80 per cent of this, or 100 acres, was the best performance we had been able to maintain, and this only by extremely careful supervision, ample stock of repair parts, proper shop equipment, provision for rapidly loading with oil, gas, water and grease twice a day when plowshares were changed, taking hot meals out to the crew in midshift, and always taking them to and from the equipment in automobiles on regular schedule time. But still another factor enters, and, while it may not be concerned with the engineering design of the tractor, it is of great importance to the operator. It is the good weather factor. We found that, on the tract in question, the days upon which it did not rain were only 75 per cent of the total elapsed days in the plowing season. This still further reduced the available time, or the *effective* plowing capacity per tractor, by another 25 per cent, or to 75 acres *per day and night of elapsed time.* Thus the total reduction factor, from the 125 acres per 20-hr. day, which it is theoretically possible to plow with such a tractor, to the 75 actual acres which can be plowed throughout any given month of the plowing season, is 60 per cent, and equipment was purchased on this basis.

The author states that if the weight per inch of width on the drivers of a round wheeler exceeds 200 lb. per in. of width, the tractor becomes *very* inefficient; that the

Digitized by Google

power consumed in rolling friction becomes a large percentage of the total developed; that in his own tractor, by throwing all the weight on the rear wheels by applying full engine torque the rolling friction is *increased* 25 per cent, and that even in a properly designed tractor the normal rolling friction on fairly soft or plowed ground will be up to 25 per cent of the total power delivered to the rim of the wheels. As a matter of fact, many of the best known and widely sold round wheelers have weights per inch of width of from 250 lb. with wheel extension rims, to 480 lb. without rim extensions, so that in general the rolling friction may be expected to exceed *greatly* the figures just given. The author then proceeds to say that if it were not for the complication and high maintenance cost of the tracklayer or caterpillar type, such a machine *might* be of *some* use, *somewhere,* say on soft ground, for instance. At this point it may be properly asked, how many times in the career of a farm tractor is it operated over such ideal surfaces as those described in the author's paper as hard macadam, dry short clover or sod? Just once, while the farmer is breaking up his new prairie sod or old grazing land. For the rest of its life on that farm it is operating over land which has already been plowed, harrowed and disked, or on corn or wheat stubble or potato fields, which are just about as soft and powdery as good farming methods can make them. In other words, why discuss the performance of a round wheeler on hard ground when 99 per cent of its work must be, and is, done on soft ground with an admitted power loss, in addition to all other mechanical losses, right at the rim of the wheel of from 25 to 100 per cent of its full rated output? Many and many a time I have operated 60-hp. round wheelers over plowed ground in hard clods, with a load of 50 ft. of heavy spike-toothed harrows, and upon coming to a part of the field where there was a genuine mulch, thereby imposing a much lighter load on the harrows, but also removing all semblance of adhesion between the rim of the drivers and mother earth, found further progress impossible; the drivers simply slipping and digging holes in which they would soon bury themselves if the power were not shut off. The author states that the overall efficiency, or the ratio of the engine horsepower to the drawbar horsepower, has never been less than 65 per cent in cases under his observation. The above case of harrowing is simply cited as one in-

Digitized by Google

stance out of a dozen situations occurring daily in farming operations of any magnitude, in which the overall efficiency is absolutely zero.

Now what are the losses in, and what will a tracklayer do on loose farm soil? The only definite comparison available at this moment is a test made by hauling a 75-hp. caterpillar, weighing 26,000 lb., at a speed of 2¼ miles per hr. on hard packed snow. The drawbar pull required was 1800 lb. This is equivalent to approximately 11 hp., or 14.7 per cent of the rated horsepower of the tractor, or an *overall* efficiency of 85 per cent, against the 65 per cent above referred to. Of course, there is an error here to the extent of the additional losses occurring in the transmission members when they are under full engine load, instead of running idle. The value of this additional loss has not been determined. A caterpillar running over a plowed field will leave as the only indication of its passage a series of splashes of powdered earth, representing former clods lying on the top of the ground, and which, having too large an area to be depressed quickly to the general surface level, are crushed. There is positively no rolling down of the ground in a pair of tracks from 2 to 6 in. deep, or more, as is always the case with the wheel type.

The author states that on sandy ground the maximum coefficient of adhesion will be about 30 per cent. The detailed specifications of "sandy ground" are not given, but since in sand the adhesion of a round wheeler is from nothing to 5 per cent, this maximum is open to discussion, as is also 43 per cent for damp sandy ground. On a test made with a caterpillar weighing 7000 lb. and having a ground pressure of 5 1/3 lb. per sq. in., less than that under a horse's hoof, the tracks were locked by a brake and the tractor was then towed by another machine. The average coefficient of adhesion was found to be about 670 lb. per sq. ft. of track surface, or 87.2 per cent of the weight of the tractor. This varied from 50 to 100 per cent, the lowest being on wet, slippery clay roads and the highest on good, hard sod. Dynamometer tests with a 120-hp. tractor weighing 28,000 lb. indicated a sustained drawbar pull of 15,000 lb., or a coefficient of adhesion of 55½ per cent, on a field covered with hard packed snow.

The author states that few machines in this country are proportioned in such a way that the full engine power can be applied on low gear without taking the front of the tractor off the ground, which interferes with steer-

Digitized by Google

ing, is dangerous and prevents full utilization of the available power. In this connection the following test of a caterpillar may be of interest. A gun mount weighing 55,000 lb. was hauled up a grade of 43 deg., the drawbar pull and the weight of the tractor indicating a coefficient of adhesion of 93¼ per cent, the surface being dry clay loam. This considers the angle of inclination to the horizontal, for on this hill the track pressure normal to the ground was only 8.05 lb. per sq. in., against 11 lb. per sq. in. with the tractor on the level. In regard to lifting the front wheel of a tractor off the ground, thus making it impossible to steer, many track-layers are now built without any front wheels at all, steering being effected by clutches on each track drive sprocket, and even if they have a front wheel they can be steered while the wheel is in the air by these clutches.

Thus it would seem that the track layer or caterpillar type is not only superior to the round wheeler in every one of the features discussed, viz., coefficient of adhesion, overall efficiency, and greater ratio of engine horsepower to available drawbar pull, but that it will actually deliver drawbar pull on soft ground, which, after all, is really the only ground with which the farmer is concerned in practice, and in which the round wheeler, unless habitually and woefully underloaded, will actually stall, and have to be dug out.

A MEMBER:—What experiments are you conducting in regard to a big caterpillar design paddle-wheel tractor?

MR. HEWITT:—I have conducted very extensive experiments on the design of lugs and grouters of various kinds, and I find that the amount of pull which will be added by any devices of this kind depends on the shearing coefficient of the soil below the edge of the grouter. Some soils have a high coefficient and others a lower one. In sand you will get practically no added pull. There are cases where the very shallow grouters are more efficient than the deep ones, because if you do not cut off the root at the bottom of the sod, and your grouter goes into the sod, it will pull more than if it simply goes down below it. The clearing of the lugs was very interesting, because I found that a lug set at an angle of about 30 deg. and inclined upward about the same angle would practically clear itself under all conditions. The reason for that is that there is a slight sliding action due to the pull on the lug, and the grouter being inclined this way enters the ground flat, and as it leaves its position is almost vertical.

Digitized by Google

I also found that it was possible to put a steel rim around the wheel 1 in. higher than the top of the lugs and run on that steel rim on the macadam road and not damage the road at all. That added very much to the operation of the machine. We can run on the road at any time, and the lugs do not touch by 1 in.

F. C. GOLDSMITH:—Have you ever conducted any experiments to determine the percentage of loss? In a paddle-wheel type you would expect a larger loss.

MR. HEWITT:—I think there is a larger loss, especially in sticky soil and wet soil.

B. S. PFEIFFER:—Did you find any difficulty in your tests when you ran on the top curve, with the caterpillar type tractor?

MR. HEWITT:—No, it is practically the same thing in the caterpillar, and a wheel twice as large in diameter will give you about twice as good results as one about half the size. The caterpillar being flat, gives you a much larger surface, but with a 6-ft. wheel we get about 20 in. in contact multiplied by the width.

MR. PFEIFFER:—Would not that pressure remain about the same—would it not be a flatter curve?

MR. HEWITT:—It might be. The caterpillar I used had only a narrow track about 6½ in. wide, and the weight per inch was pretty high on it. It was not a very good design of machine.

DENT PARRETT:—From the practical standpoint, in the first place, there is a very small percentage of work done on ground within 24 hr. after it is plowed; either the ground is harrowed at the time it is plowed or else the disking or harrowing operation takes place long enough after the plowing so that in most cases a crust is formed on the ground and the weight-carrying capacity of a wheel is not in direct proportion to its width. In other words, it takes a certain effort to break down the crust. Therefore, a narrower wheel will carry a higher proportion of load per inch of weight than a wide one. Another factor which comes in is that it takes a certain amount of pressure to push each lug into the ground, and a tractor wheel equipped with grouters would have a greater weight-carrying capacity than a plain wheel would.

I had a report from Texas which showed that a three-bottom outfit plowed 280 acres of land in 40 days. They were not in the field over 10 hr. a day and in that time the tractor was oiled and cared for. There were prac-

Digitized by Google

tically no repairs. This may be a little higher than average results, but it shows what can be done on a farm where the tractor is properly operated in an aggressive way.

MAJOR L. W. CHASE:—I have found in the Central West that farmers do not care so much about the cost of work as the opportunity to get their work done quickly and at the proper time. One big farmer in Nebraska who, due to the use of tractors, has been able to reduce the number of his horses from sixty to eighteen, made the statement that by plowing at the proper time with tractors he could get 5 bu. more wheat per acre than he would if he let his plowing drag along through the season; and because of that he has purchased a third large tractor. Plowing is not all of the farm operation today; it is one around which we talk because it is one point that we can get down to figures on, but there are many operations that the tractor will do, and do more quickly and often more cheaply than horses. One illustration is that farmers can haul manure with an ordinary three or four-bottom tractor as cheaply as they can haul it with horses. This was before war conditions. During the war the tractor has entirely superseded the horse as to cost of many operations.

It is ordinarily expected that a tractor should run on about 2 gal. of kerosene per acre. But fuel consumption is not the deciding factor. It is believed that the farmer wants a tractor that will do all kinds of operations and that do them at least 100 days per year and for several years, even at the cost of more fuel.

In these tests of wheels, I understand a trailer was used. What would be the effect as to rolling friction if they were tractor wheels? What is the relation between the trailer wheel and the tractor wheel?

MR. HEWITT:—I think the tractor wheel would act exactly the same as the trailer wheel.

MAJOR CHASE:—I have understood that the tractor wheel is different from the trailer wheel in that it comes in contact with the surface of the ground on the front half of the wheel only, while the trailer wheel has a certain percentage of contact behind the line that passes vertically through the center of the wheel. This was the result of some investigation that Professor Seaton started to conduct at one time, and I have by observation in the various tractor tests noted the same condition. It was because of this that I felt there would be a

Digitized by Google

difference in the rolling resistance between a tractor and a trailer wheel.

Another point touched upon in the paper is the matter of the length of lugs or grouters, and Mr. Hewitt even speaks of the smooth wheel. A smooth wheel might do fairly well under ideal conditions, but you all know that when you take your automobile out and start to church on Sunday, it takes only about 2 rods in a mud hole to put the car out of commission. Now it is the same thing with the tractor; it takes only about 10 ft. of hard surface with a little slippery mud on top of it to cause the wheels to slip. For that reason I feel that the paper is a trifle misleading; you cannot under any circumstances get along on farms without grouters of some kind.

Mr. Hewitt spoke about the load per inch of weight being a direct function of the drawbar pull of the wheel. Does not the diameter of the wheel also introduce a function, which is not stated?

MR. HEWITT:—It works directly as the diameter.

MR. GOLDSMITH:—I regret very much that the kind of soil upon which the tests of the friction of the wheel on the ground were made is not stated. It seems to me, from what I have seen at the show, that most manufacturers have very long cleats. If the conclusions drawn by the author are true, the shear is entirely at the bottom of the cleat and a ½-in. cleat would be as good as a 3 or 6-in. one.

E. A. JOHNSTON:—The experience of tractor manufacturers is that if you supply tractors in many different portions of the world you will be compelled to supply many different forms of cleat and many different widths of tire. The number of pounds per inch of tire varies greatly with the conditions under which the tractor operates. There are a great many things to consider, including the road laws of different countries.

Digitized by Google

AUTOMOTIVE APPLICATIONS OF MARINE ENGINES IN THE WAR

By George F. Crouch[1]

THE application of the marine internal-combustion engine to the British ML class of 80-footers and to the American 110-ft. class of submarine chasers, undoubtedly constituted the most important development along this line of automotive work. With a hull form similar to that of an enlarged runabout, driven by a pair of six-cylinder Standard marine engines rated at 220 b.-hp. at 460 r.p.m., the boats of the ML class averaged about 20 knots. A total of 720 boats of this type were built and the class as a whole proved very satisfactory.

In the development of the 110-ft. SC class, the requirement of seaworthiness was made of greater importance than speed. Each boat carried three six-cylinder Standard engines identical with those used in the British boats, driving them at about 17 knots. Although rather uncomfortable, as in the case of any small vessel, the 110-ft. boats proved wonderfully successful in heavy weather; about 450 of this class were built.

The 220-b.-hp. engines have six cylinders of 10-in. bore and 11-in. stroke. They are started by air and are of the direct reversing type. Many unique features are found in their construction. Some idea of the magnitude of the undertaking is given by noting that the total of 700,000 b.-hp. built during a little over three years would be sufficient to drive twenty-five large super-dreadnaughts of the Arkansas class.

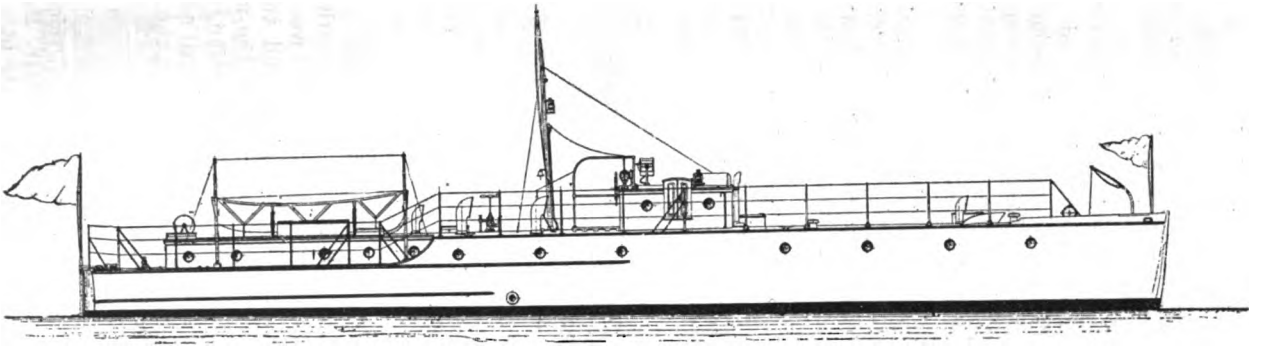
The object of this paper is to present to the Society a description of a few of the boats and engines which have been of service to the Allies and to the United States during the war and to draw conclusions as to the effect of the experience gained with these boats on the design of hulls and engines for general marine use.

The British M L Class

When it became apparent that the submarine offensive was a large part of the German plan, the British naval authorities decided that one of the most effective defensive measures consisted of a large fleet of small motor boats of good speed and seagoing qualities, which could

[1]Technical editor, Motor Boat Publishing Co., New York City.

Digitized by Google



Elevation of the 80-Ft. British M L Chaser

Digitized by Google

search out the submarine and destroy it with depth bombs. For the amount of money expended, this scheme would provide a patrol over an immense sea area and because of their shallow draft the boats would be immune from torpedo attacks.

Plans submitted by American manufacturers were approved and the work of construction started. Within 488 days one American company delivered the entire order of 550 of these boats to the British Government, and additional orders from other Allied nations have since brought the total up to about 720 boats built by them to this design.

Their remarkable success in hunting the submarine and in working in conjunction with the larger naval vessels has been even more surprising to those of us who have followed motor boat work than to the uninitiated. It is not my intention to go into the details of the part these boats played, for that can be found in many stories already in print, but I cannot refrain from mentioning that they had a big share in the marvelous exploits of the British Navy against the submarine bases of Ostend and Zeebrugge.

DETAILS OF THE M L CLASS

General Dimensions—

Length overall	79 ft. 7 in.
Length on water-line	78 ft. 9 in.
Extreme beam over guards	12 ft. 5 in.
Beam on deck	12 ft. 1 in.
Draught to bottom of deadwood	3 ft. 1 in.
Full-load displacement	78,000 lb.

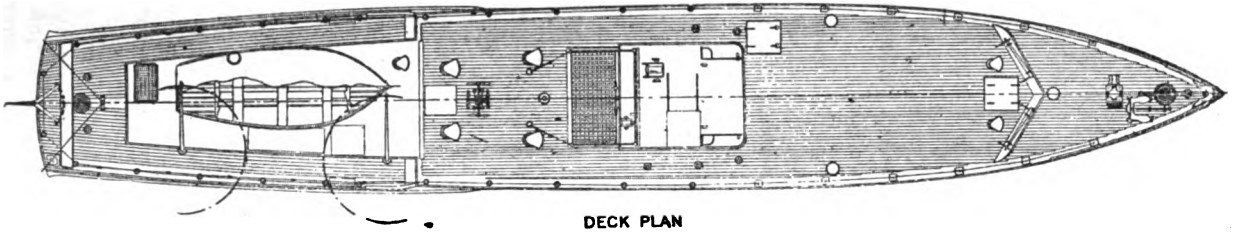
Construction The hulls are lightly built, but are elastic and strong. In estimating their strength it must be remembered that the strength of small wooden vessels depends more upon their fastenings and the accuracy with which the parts are fitted than on the use of large and heavy parts. To speed up construction, every piece of wood in the hull was drawn out in detail and prepared in advance of the time it was required on the boat.

Principal Scantlings

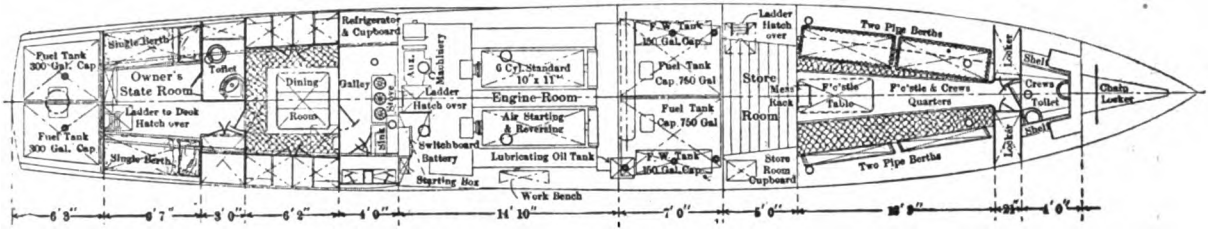
Planking, yellow pine 1⅛ in. thick

Frames, white oak steam-bent, 1¾ in. sided by 1¾ in. molded, spaced 12 in. center to center. Heavy frames at bulkheads, white oak, 2¼ by 2¼ in.

Digitized by Google



DECK PLAN



INTERIOR ARRANGEMENT

DECK AND INTERIOR PLAN VIEWS OF THE 80-FT. ML CLASS

Digitized by Google

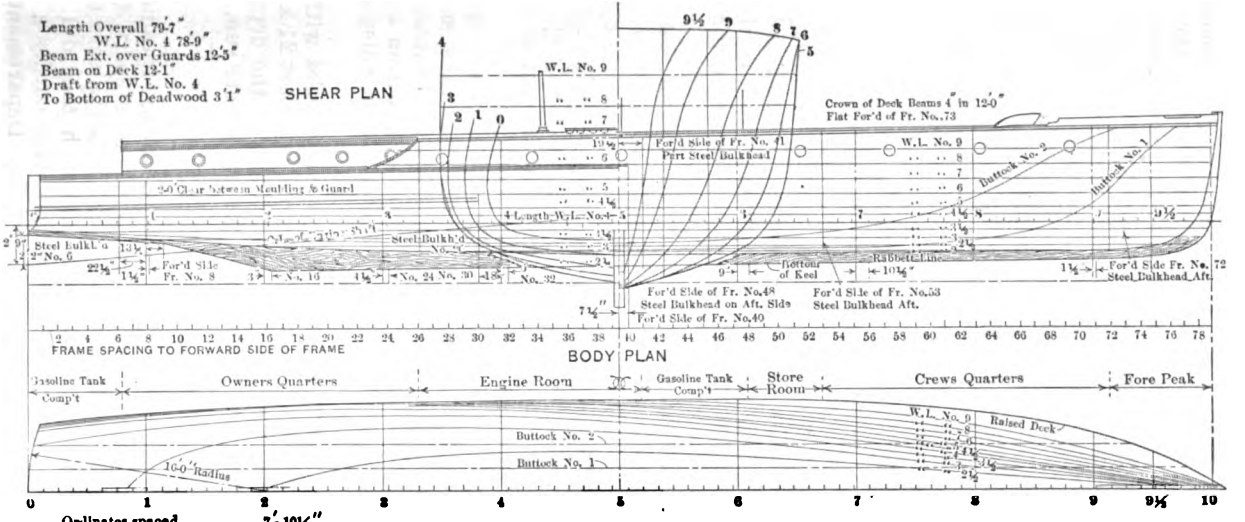
Deck planking, Oregon pine laid in strips 2⅝ in. wide by 1⅛ in. thick
Deck beams, white oak sided 1¾ in., molded 2½ in.
Keel, white oak sided 4 in.
Keelson, yellow pine 4 by 5 in.
Floors, galvanized wrought iron 1½ ft. wide, ¾ in. thick at center tapered to ⅜ in. at ends
Knees connecting frames to beams, wrought steel ⅜ by 3 in.
Upper clamp, yellow pine 1¾ by 4½ in.
Main clamp, yellow pine 1½ by 5½ in.
Hogging clamp, yellow pine 1½ by 5½ in.
Side keelson, yellow pine 1¾ by 6½ in.
Bilge stringer, yellow pine 1½ by 4½ in.
Six steel bulkheads about ⅛ in. thick placed at frames Nos. 6, 26, 40, 47, 52 and 71

The steel bulkheads at the ends of the gasoline tank compartments are made gasoline-tight by careful workmanship and the use of a special paint composed of litharge, glycerine and shellac.

The outboard profile and arrangement plans of this class are shown. It will be noticed that the difference in appearance between one of these boats and a modern express cruiser of about the same size and power, is slight, except for the long fore deck of the M L class, which is kept clear of all obstructions to give a wide angle of fire to the short caliber 13-pounder gun mounted just ahead of the low chart-house over the midship fuel tanks. This gun is not shown in the plan, and it may be noted that in the later boats it was found necessary to build up a permanent shelter for the helmsman just aft of the trunk.

The line drawing is also reproduced. In form these boats are nothing more than big runabouts. In fact, if the scale were changed to give a length of about 35 ft., they would have not only the proper proportions, but about the correct displacement for a high-speed runabout of that size. The wide, flat transom, deeply immersed when the boat is at rest, produces a form of small resistance at high speed, but creates a big wave at slow speed. The bow lines are long and fine. This combination of wide stern and fine bow has never been considered a desirable type for outside work in heavy weather, but the results in this case have been surprisingly good. Irvin Chase, the naval architect who designed the boat, was forced to use this form because of the high speed for the power demanded by the British Government. Another form, perhaps a more conventional seagoing type,

Digitized by Google



LINE PLAN OF 80-FT. BRITISH ML SUBMARINE CHASER

Digitized by Google

would have demanded increased power and reduced the radius of action of the boats materially. Considering the restrictions imposed by these requirements, there was no possibility of using any other type, and although the boats are very uncomfortable in a heavy sea, which is true of any small craft no matter what its model, not one of the class has been lost through stress of weather.

Armament The armament consists of a short caliber, 26-in. recoil, 13-pounder gun mounted on the fore deck, four or five depth bombs charged with 250 lb. of TNT, 16-lb. lance bombs and two machine guns. Recoil pressures are kept down in the 13-pounder by using a low muzzle velocity and an unusually long recoil. The depth bombs are dropped off the stern by a releasing apparatus.

Machinery The powerplant consists of a twin-screw installation of two six-cylinder, four-cycle, air-starting and reversing Standard engines having cylinders of 10-in. bore and 11-in. stroke. These engines, which are rated by the builder at 220 hp. at 460 r.p.m., are directly connected to the three-blade propellers, 42 in. in diameter by 63-in. pitch.

An auxiliary set includes an air compressor, a 4½-kw. generator and a bilge and fire pump. The two power cylinders of the auxiliary engine are 4½-in. bore by 4½-in. stroke, and have the air compressor cylinder between them. The fire and bilge pump has a capacity of about 50 gal. per min., and can be thrown in and out of action by a gear working in an eccentric mounting.

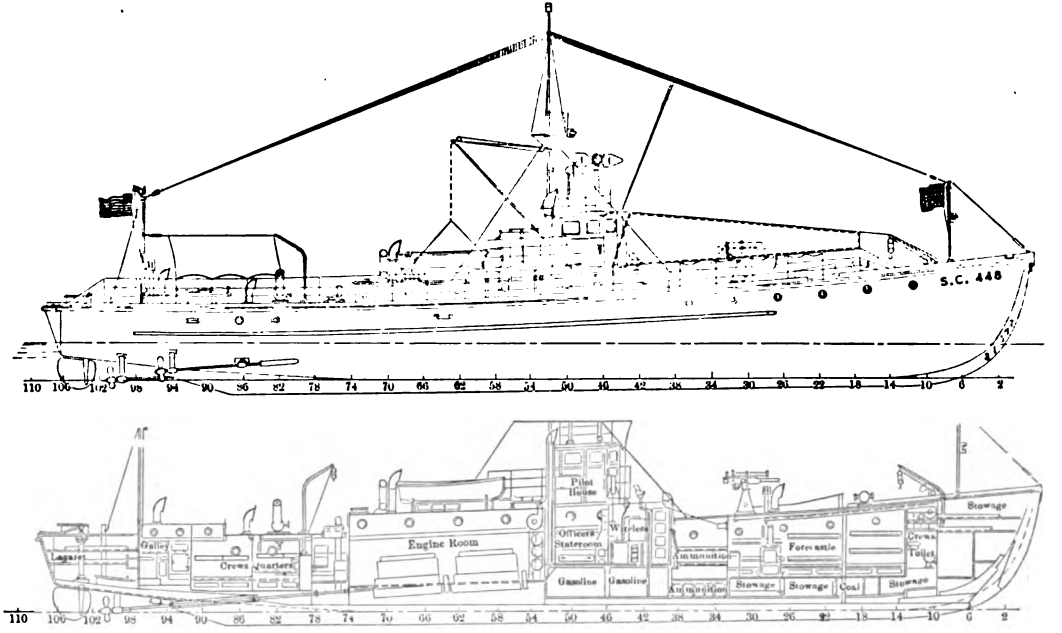
Gasoline is stored in built-in tanks in a compartment ahead of the engine-room and also in a smaller compartment at the extreme stern. The total capacity of the tanks is 2100 gal., giving a radius of action of 750 nautical miles at 19 knots, and 1000 nautical miles at 15 knots.

The maximum speed obtained on trial varied with the different boats from about 19¼ knots to almost 21 knots, due to the variation in the engines and to the depth of water on the courses over which the trials were run.

The 110-Ft. S C Class

Early in 1917, when war with Germany became inevitable, the Navy Department began to prepare for a great fleet of submarine chasers. Many boats were taken over from private owners, and, although they did good work, it was soon realized that they were hardly a suitable type for the purpose. The Navy Department ob-

Digitized by Google



OUTBOARD AND SECTIONAL ELEVATIONS OF THE UNITED STATES 110-FT. SUBMARINE CHASER

Digitized by Google

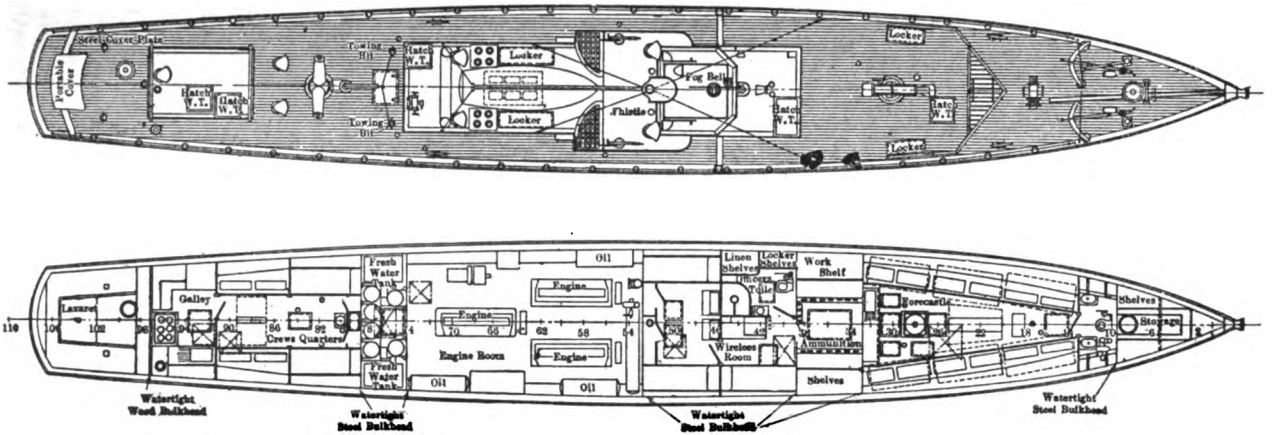
tained the services of A. Loring Swasey, later Lieut.-Commander,. a Boston naval architect responsible for many of the best of the privately owned motor yachts, and, working in conjunction with the Bureau of Construction and Repair of the Navy Department, he produced the design of the 110-ft. S C class.

With the results of the M L class as a guide, the S Cs were given a length of 110 ft., which was considered the maximum for which stock engines could be obtained in requisite quantity. Then, too, it was decided that this length was about as great as the average boat-building yards could handle. Steel was out of the question as a material for construction because of the demand for large steel ships, which took all the available supply and filled all the steel shipyards. The first contracts were let April 16, 1917, and since this first order of a few more than 350 boats there have been smaller repeat orders, making the total of this class about 450. Contracts were placed all over the country, some even on the Pacific coast, whence the boats when completed were brought around through the Panama Canal. It is gratifying to the motor boat industry to know that the Navy Department realizes how these contracts were carried out.

Since the armistice was signed many stories of these boats have found their way into print, and even the worst grumblers admit that they did more than their share. We have the statement of Secretary of the Navy Daniels that the S C vessels accounted for 40 per cent of the total number of submarines destroyed by the Navy; the fleet of converted yachts is credited with 30 per cent and the destroyers with 20 per cent. The chasers were out with the battleship fleet in the worst weather experienced in years and came through in fine style. About 235 of them have crossed the Atlantic, and it has been found that they do much better under their own power than when towed by a consort. One of them, which had been sold to France, went into port under a makeshift sail of blankets rigged on her mast, after having been separated from her convoy in a heavy storm. She had run out of gasoline and oil and was 39 days in reaching port, but made it safely. The boats have been tested in every conceivable manner, and in every case have made good. In all the immense shipbuilding, aircraft and tank program, nothing has come closer to fulfilling every expectation than this S C class of 110-footers.

Construction The hulls are substantially built, the ma-

Digitized by Google



PLAN VIEWS OF THE UNITED STATES 110-FT. SUBMARINE CHASER

Digitized by Google

terial being of liberal size. There has been no attempt to cut down weight but rather to produce a boat that can stand up to any sea. In general, the construction is heavier than on yachts of the same size and power.

DETAILS OF THE 110-FT. S C CLASS

General Dimensions

Length overall	110 ft.		
Length on designed load water-line	105 ft.		
Extreme beam over guards	15 ft.	4¾	in.
Beam to outside of planking	14 ft.	8¾	in.
Draught to bottom of deadwood	5 ft.	11	in.
Displacement, full-load, about	75 tons		

Principal Scantlings

Planking, yellow pine 1¾ in. thick

Frames, white oak steam-bent, sided 2½ in., molded 3 in., spaced 12 in. center to center. Heavy frames at bulkheads and at points where special strength is needed 4 in. sided by 3 in. molded

Deck planking, Oregon pine laid straight fore-and-aft in pieces 1⅝ in. thick and 3 in. wide

Keel, yellow pine sided 7 in., depth according to plans

Keel battens, white oak sided 9 in. by 8 in. molded

Floors, white oak regular floors on every frame 2 in. thick; heavy floors in engine space and under gun foundations 3½ in. thick

Upper clamp, yellow pine 3¼ by 3¾ in.

Main clamp, yellow pine 2¾ by 4¾ in.

Hogging clamp, yellow pine 2 by 8 in.

Six steel bulkheads about 7½ lb. per sq. ft. on frames Nos. 10, 33, 37, 53, 74 and 78

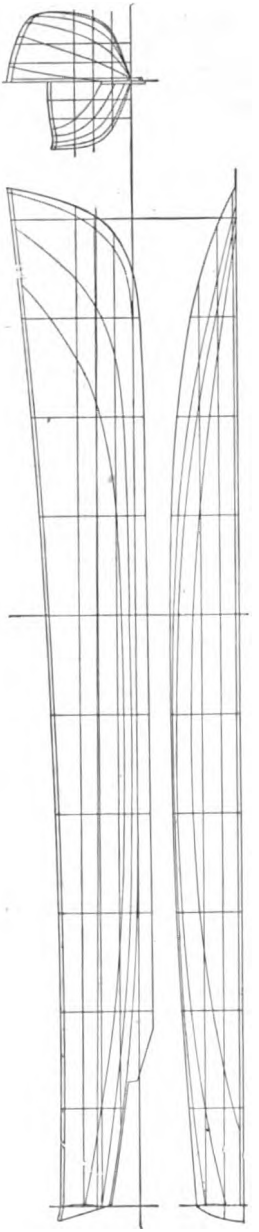
The outboard and inboard profiles of these boats is shown, as well as the deck and general arrangement. The forecastle is roomy and comfortable for a small boat, and is heated by a stove. This stove does more to make the crew comfortable than any one other item of equipment. Notice the wireless room on the starboard side over the gasoline tanks. The floor over the tanks is supposed to be vapor-tight, but the loss of one of these boats by an explosion caused by a wireless spark while taking on fuel confirmed the general belief that the gasoline tanks and the wireless should be kept as far apart as convenient arrangement will permit. Forced-draft blowers, driven by electric motors, ventilate the forecastle and the engine room when the hatches are closed in heavy

Digitized by Google

weather. The galley is of ample size and very fully equipped, and the helsman is well protected from the sea. Taken as a whole, there has been some appreciation of what a few comforts mean to the efficiency of the crew of such a boat. Comfort is comparative, however, and the landsman would consider the life very hard until inured to it. The boats carry a crew of two officers and twenty-four men.

The line drawing reproduced is not an official plan, but is a close approximation to the form. The lines show a form which all experienced men will immediately accept as an excellent one for sea work. The water-line forward is fuller than in the M Ls and the stern much finer. All sections show a sharp rise of floor, which becomes even sharper at the ends. At the stern there is a transom much like that of a dory in shape. The heavy weights of the machinery, fuel and armament are kept well in toward the center of the length, so that the bow can rise easily and quickly to the sea. Owing to the fine lines of the after body, there is a tendency for the boat to "squat" at top speed.

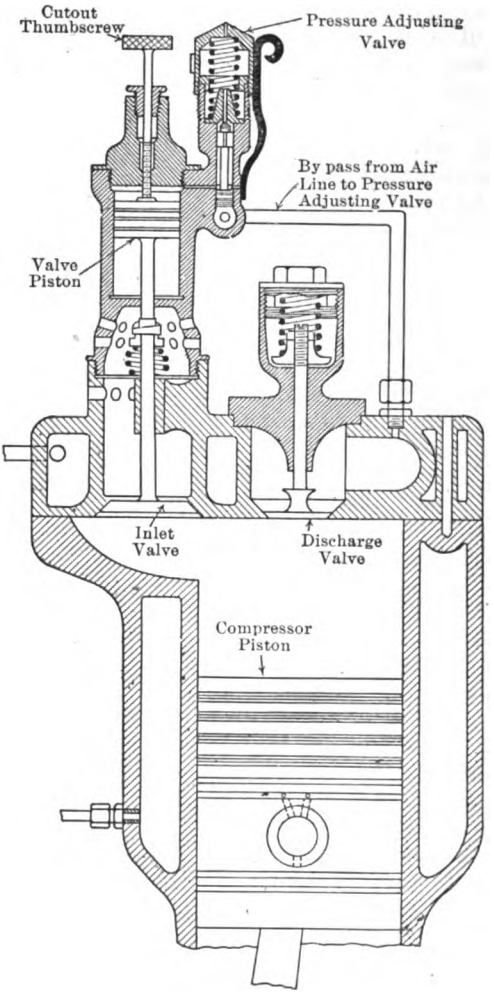
Armament The armament consists of a 3-in. Poole gun of 23 calibers, having a 28-in. recoil, mounted on the fore deck, two machine guns mounted on the wings of



Line Plan of 110-Ft. Submarine Chaser

Digitized by Google

the bridge and a depth charge projector, commonly called a Y-gun, on the after-deck. Six depth bombs containing 300 lb. of TNT are carried. The 3-in. gun is much the same as that used on the British M Ls and can be con-

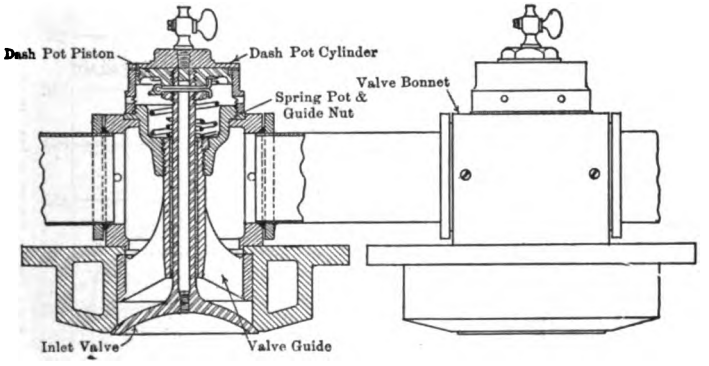


AIR COMPRESSOR

verted into an anti-aircraft gun if necessary. The Y-gun is the unique feature of the armament. It takes its name from its shape, which is exactly that of the letter

Digitized by Google

Y with arms pointing out to each side at an angle of about 45 deg. from a common chamber at their junction. This chamber is provided with a breech mechanism which takes a blank 3-in. shell, and when fired it blows out plungers fitting into the upper ends of the arms of the Y. These plungers carry the depth bombs on their outer ends, and bombs, plungers and all are shot overboard. This device places a charge on either side of the assumed position of the submarine, so that one or the other of the bombs is almost certain to "get it." All horizontal recoil is balanced, leaving only a downward thrust, which is easily taken care of by pillaring under the deck. The depth bomb, not the 3-in. gun, is the real weapon of the chaser.



INLET VALVE

A large measure of the effectiveness of the boats in hunting out submarines was due to remarkable listening devices by which the sound of a submarine could be determined and differentiated from that of other ships. This sound was located exactly in direction by plotting the reports of three boats in constant communication by wireless. This device is one of the dark secrets of the Navy and no details are available. The use of an engine which could be stopped and started instantly contributed to the efficiency of the installation of the device on these boats.

Machinery The boats are driven by triple screws each directly connected to a six-cylinder 220-hp., air-starting and reversing Standard engine. This is exactly the same engine that was used in the British M Ls, and was

Digitized by Google

already being produced in quantity when our chaser program was started. The original propellers were three-bladed, 36-in. diameter by 63-in. pitch; later changed to 39-in. diameter by 57½-in. pitch. Even these seem small for the power of the engine. The center engine can be uncoupled from its propeller shaft to allow the wheel to turn without dragging when the boat is cruising under the two wing screws. The auxiliary machinery set is a duplicate of that in the M Ls, previously described.

Gasoline is carried in four large shaped tanks fitted in the compartment forward of the engine room under the floor of the officers' quarters. The total capacity is 2400 gal., which gives a radius of action of about 1000 nautical

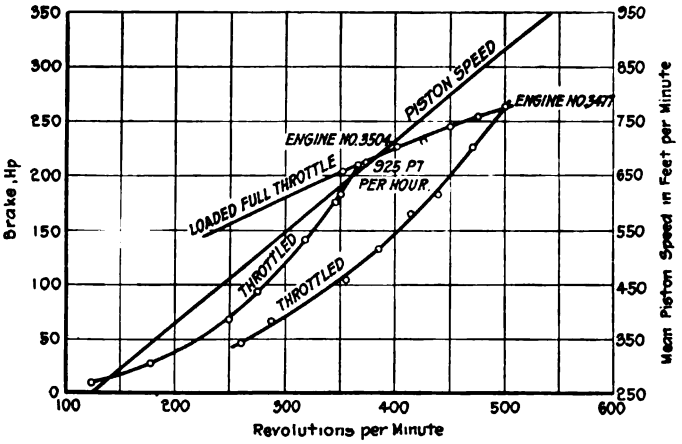


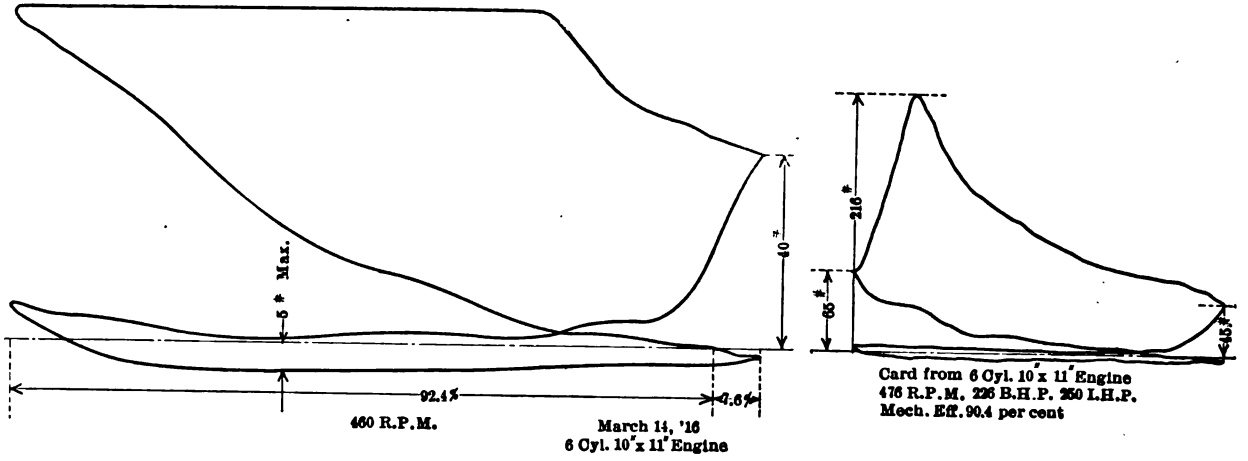
CHART OF TEST RUNS OF ENGINES USED IN THE UNITED STATES 110-FT. SUBMARINE CHASER

miles at a cruising speed of 12 knots. The maximum speed with all three engines running is between 16 and 17 knots. About 1½ to 1¾ knots more is obtained under all three engines than under the two wing engines alone.

THE 220-HP. STANDARD ENGINE

This engine, used on both M Ls and S Cs, is a stock model. In 1904 thirty small steel torpedo boats about 100 ft. long were built for the Russian Navy and were powered with the early model of this engine. The present model is changed in some details, but nothing of any account has been altered since that time. I believe it is

Digitized by Google



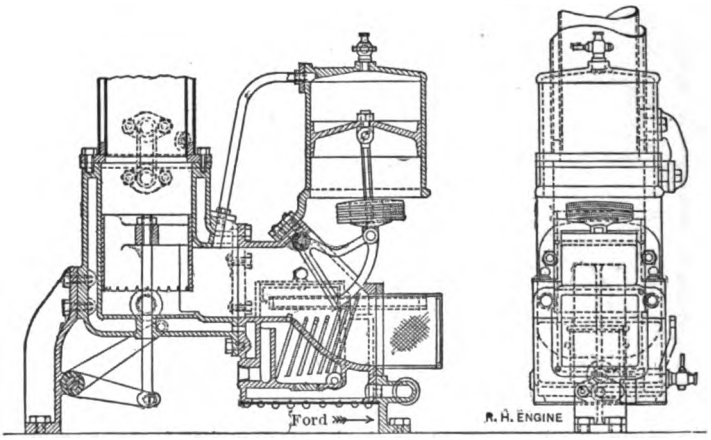
INDICATOR CARDS OF ENGINES USED IN THE UNITED STATES 110-FT. SUBMARINE CHASER

Digitized by Google

unique to find a time-tried stock machine used in such quantities in any Government work.

The job of producing all these engines was immense even with the best of modern production methods. In a little over 3 yr. the Standard Motor Construction Co. has delivered about 700,000 b.hp. of this model alone. That is power enough to drive twenty-five of the large super-dreadnaughts such as the Arkansas and more than will be needed for our proposed battleship program for the next 3 yr. It is only by making such a comparison that the size of this submarine chaser undertaking is comprehended.

The cylinders are 10-in. bore by 11-in. stroke. The normal speed for which the engine is designed is 460

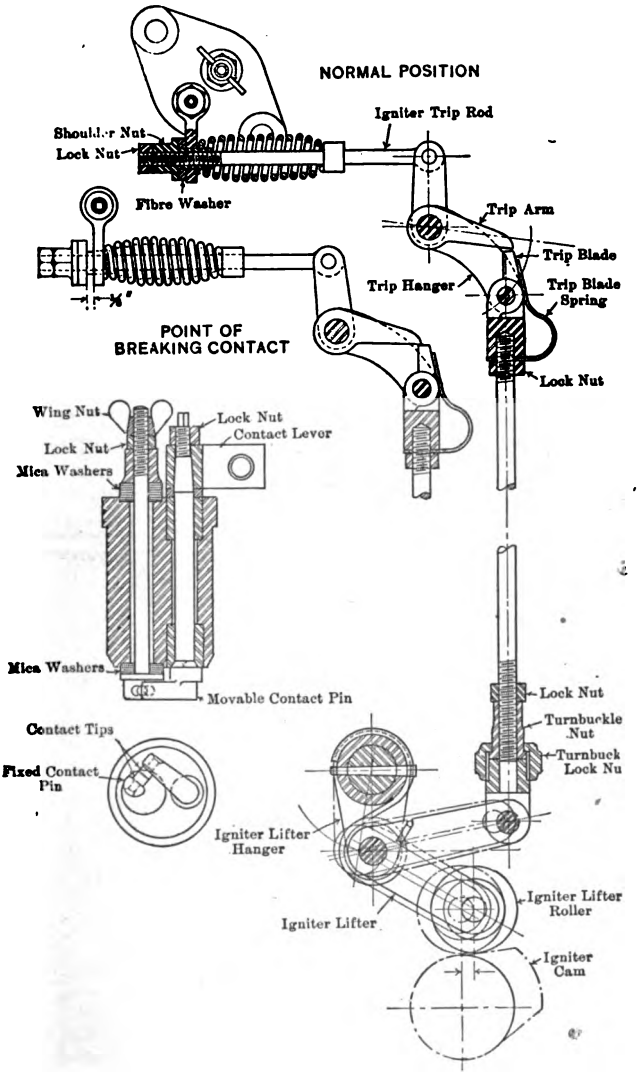


DETAIL ARRANGEMENT OF THE VAPORIZER

r.p.m. Its rating at this speed is 220 b.hp., but the actual power is close to 250. The weight of the complete engine is 6300 lb.

Starting and reversing are accomplished by admitting air through a cam-operated valve into a small chamber, from which it passes into the combustion chamber by forcing open a spring-loaded non-return check-valve. The cam-operated valve is timed to admit air on the regular working stroke, and, as it is exhausted on the regular exhaust stroke, it does not interfere with the suction or the compression of the gasoline-air mixture. If the mixture ignites, the resulting pressure within the

Digitized by Google

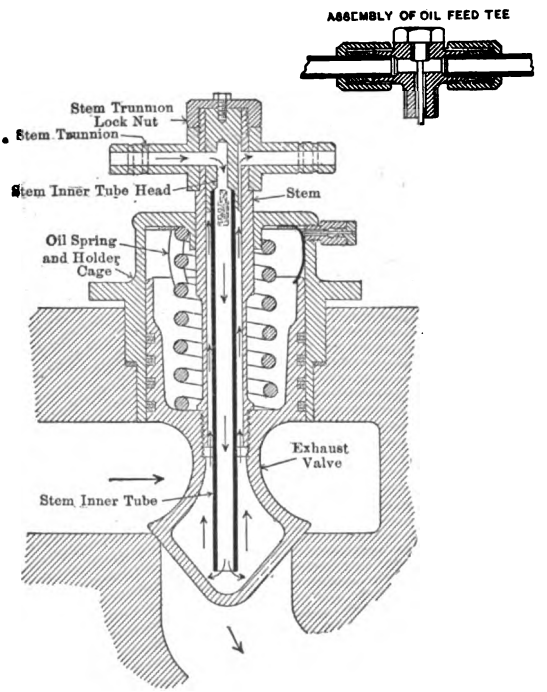


Igniter Gear Used on the Engines of the United States 110-Ft. Submarine Chaser

Digitized by Google

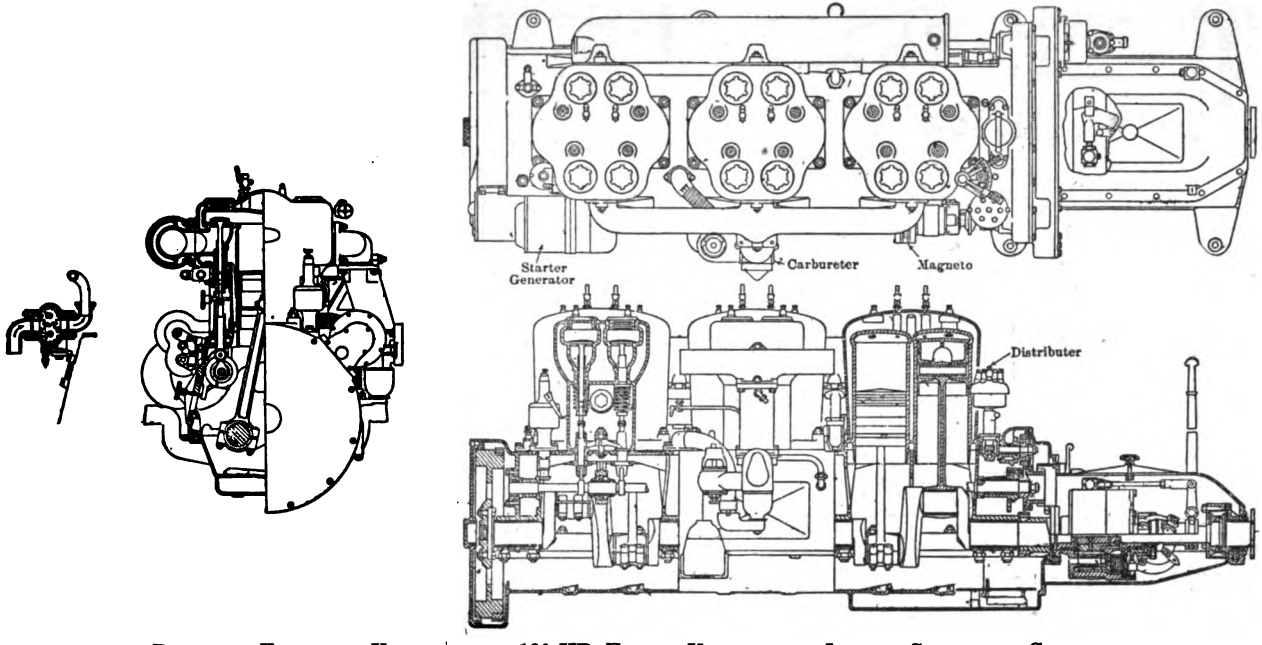
cylinder holds the check-valve against its seat and prevents the entrance of starting air, even though the mechanically operated air-valve be open. As soon as the engine is firing regularly, the camshaft is shifted longitudinally to running position, for either the ahead or astern direction, and this shift moves the air-valve cams out of line with the followers. The camshaft, which operates the igniters and exhaust valves, as well as the air-starting valves, is shifted longitudinally by a long lever at the after end of the engine. This is shown in the neutral position for ahead or astern motion, thus bringing into operation entirely different sets of cams timed to function properly for the desired direction of rotation.

It should be noted that when the engine is stopped by cutting off the ignition and the camshaft is brought to neutral position after having been run in one direction, it can be started in the reverse direction nine times out of ten without using any air, since the shift of the cam-



DETAIL ARRANGEMENT OF THE WATER-COOLED EXHAUST VALVE

Digitized by Google



PLAN AND ELEVATION VIEWS OF THE 180-HP. ENGINE USED ON THE ITALIAN SUBMARINE CHASERS

Digitized by Google

shaft produces a spark at the proper igniter if the switch is closed before the camshaft is shifted. This reversing is so quick and powerful that the 110-ft. chaser can be

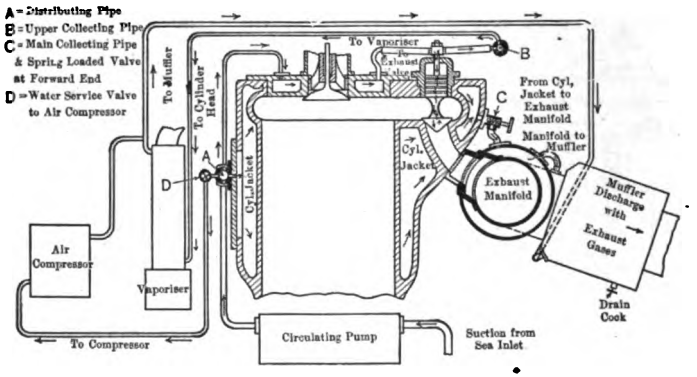


DIAGRAM OF CIRCULATING WATER SYSTEM

stopped in a couple of lengths when going full speed ahead.

Air for starting and reversing is stored at a pressure of 250 lb. per sq. in. in cylindrical steel tanks, in which the desired pressure is maintained by a compressor at the after end of the engine.

Automatic inlet valves, a type long ago discarded in automobile work where great speed range is required, are used on the engine. In these slow-speed engines, automatic valves function efficiently, as can be seen by reference to the low scale indicator card reproduced. These inlet valves have a clear diameter of 4½ in. and are fitted with a piston on the upper end of the stem working in a dashpot to prevent fluttering and hammering, and with a stiff bumper spring to limit the lift. It may be of interest to note that the builder of the engine is about the only builder of marine engines now employing the automatic inlet valve, and this is used only on the heavy-duty types.

The details of the water-cooled balanced exhaust valves are also shown. These valves are lifted from their seats by rocker-arms acting on trunnions attached to the top of the valve-stem. The rocker-arms are actuated by pull-rods connected to the cam-followers. Cooling water enters and leaves the valve through the trunnions, which

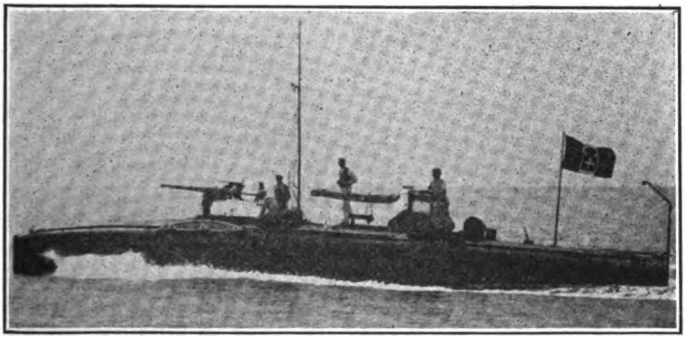
Digitized by Google

are connected by short lengths of rubber hose to the supply and discharge pipes. The valve has a clear diameter of 3½ in. and a lift of ¾ in. on the ahead motion and ½ in. on the reverse. About 90 per cent of the pressure of the valve against its seat is neutralized by the balance piston.

Make-and-break low-tension ignition is used. Current for ignition when starting the engine is taken from a storage battery, and for running is supplied by a low-tension alternating-current magneto driven by the engine.

Cooling water is taken from the sea and is forced through the jackets by a large double-acting plunger pump mounted at the fore end of the engine, driven at one-fourth crankshaft speed.

The carbureter is of special construction. It will be noticed that the fourteen spray nozzles are uncovered in sequence by a curved shutter, lifted by the vacuum above a piston working in a cylinder which communicates with the mixing chamber by a tube. This carbureter is without adjustment other than that obtained by changing the weight to be lifted by the piston. No float is used, as the gasoline is pumped into the bowl from a service tank placed below the carbureter level and the surplus delivered to the bowl returns to the tank through an overflow pipe. The air supply is not heated, but both the



THE TYPE OF SUBMARINE CHASER USED BY THE ITALIAN NAVY

carbureter and the riser from the carbureter are jacketed with hot water. For easier starting in cold weather the cooling water discharge from the small auxiliary engine can be turned into these jackets. The main moving parts

Digitized by Google

are lubricated by individual oil leads from a force-feed lubricator, each lead being set to deliver the requisite amount of oil direct to the part. Minor parts are oiled by hand about once an hour. Approximately 1440 hp.-hr. are obtained from 1 gal. of lubricating oil. Sheet-metal plates are fitted outside the steel column framing to prevent oil from splashing around the engine room, and a sheet-metal pan under the bed-plate keeps the oil out of the bilge.

An indicator card taken at 476 r.p.m. is reproduced. This card is not at all satisfactory, as it shows strongly the effect of the inertia of the piston, pencil gear and drum of the indicator, but it is given as the only one available at present. A maximum compression of about 65 lb. per sq. in. gage is obtained with a combustion chamber volume of 311 cu. in., a compression ratio of 3.87. An analysis of this card shows a volumetric efficiency of about 85 per cent after allowance for inertia errors.

The results of tests with a hydraulic brake are given. The curves obtained by throttling will follow somewhat the same law as if the engines were connected directly to the propellers. Fuel consumption at full load is approximately 0.7 lb. of gasoline per hp.-hr., which will doubtless seem high to those who have been working with engines having 100-lb. compression and over, but it is exceedingly satisfactory in actual service.

58-Ft. Italian Chasers

A type of boat entirely different from anything built in this country for chasing submarines is that which the Italians have used in the Adriatic. Although the hulls were designed and built in Italy, the motive power consists of a pair of 200-hp. eight-cylinder Sterling engines made at Buffalo, N. Y. The boats are 58 ft. long, 9 ft. wide and draw 30 in. The total weight of the complete boat with equipment is about 30,000 lb. To get strength with minimum weight, the planking is in three layers with canvas between each. The form of these boats is similar to a concave V-bottom runabout with the chine sweeping up forward to the stem head. The concave of the forward sections is very pronounced. They are said to make a speed of 26 knots. The boats are armed with a small high-power gun forward, which can be elevated for anti-aircraft use, two machine guns aft, and a num-

Digitized by Google

ber of mines. It has been reported that it was boats of this class, carrying deck torpedo tubes, that entered the harbor of Pola and destroyed two Austrian battleships.

The Sterling Engine

The engines in these boats are in decided contrast to the heavy-duty type used in our chasers, and in all their details approximate the heavy automobile or truck type. The general arrangement of a six-cylinder model of this engine is shown. The cylinders, 5½-in. bore by 6¾-in. stroke, are cast in pairs and are of conventional T-head design, with long water-jackets extending to the base flange. When built for high-speed work, the engine develops 180 hp. at 1200 r.p.m., and 200 hp. at 1400 r.p.m. Its total weight, including reverse gear, electric starter and generator, is 2400 lb. In sharp contrast to the open construction of the 220-hp. Standard engines, this Sterling engine is entirely enclosed, even to the flywheel. An electric starter which engages with teeth cut in the rim of the flywheel is used. Reversing is obtained by a clutch and reverse gear housed in an oil-tight case and lubricated by oil under pressure led through the hollow crankshaft. The ignition system consists of a high-tension dual two-spark magneto, the plugs being placed in water-jacketed bosses in the cylinder-heads. Two carbureters are used, each feeding a set of four cylinders. All parts of the engine are lubricated by a self-contained system which forces oil under pressure through the hollow crankshaft to all main bearings. The oil collecting in the base is cooled by a water-jacket on the bottom of the sump and is filtered before being again pumped to the bearings. A counter-balanced type of crankshaft is used. Fuel consumption at full power is approximately 0.6 lb. of gasoline per hp.-hr.

Other Boats

There are many other craft which should be included in a complete summary of the activities of our marine engine and hull builders, but exact data have not been accessible on either hulls or engines. An important fleet of thirty-one boats 60 ft. in length was built by the Greenport Basin & Construction Co. Each boat was powered with three eight-cylinder Van Blerck engines. These boats were of V-bottom form and were required to exceed 25 knots on trial. They were armed with a Russian 3-

Digitized by Google

pounder forward and two machine guns aft, and operated against submarines in the Black Sea.

The engines were 6-in. bore by 6-in. stroke with T-head cylinders cast in pairs. As they were installed in the boats, they delivered about 165 hp. each at 1200 r.p.m. The total weight, including electric starter and reverse gear, was about 2400 lb. In general characteristics this engine and the 200-hp. Sterling are similar.

Some Deductions from Chaser Experience

With regard to the hulls, the statement can be made that not one of the types described is suitable for commercial purposes except perhaps a modified form of the 110-ft. S C model. With added beam and much less power this model would make a splendid off-shore fishing boat, as it is essentially a seagoing type. Each one of the forms described lends itself excellently to conversion into privately owned yachts and cruisers, particularly the 80-ft. M Ls. Since speed was a requisite in all these boats, they carry more power than is advisable even for yacht work, and far more than can be used in commercial craft for the transportation of cargo.

The horsepower required to propel a boat varies approximately as the cube of the speed and may vary as the fourth, fifth or even the sixth power of the speed, if the form is not suitable for the speed. It requires as much power to get the last 1¾ knots in the 110-ft. chasers as it does the first 12 knots. When cargo is to be carried cheaply the speed must be kept down as low as the conditions of the particular route and trade will permit. The result will be a good-sized boat of lower power, and this boat must have a large, slow-turning propeller, since no one has produced or even suggested a high-speed propeller to work efficiently on a big boat of moderate speed.

To realize the advantages of lighter weight, reduced first cost, decreased space required and general ease of handling inherent in engines running between 400 and 1200 r.p.m., some sort of transmission must be used between the engine and the propeller-shaft. It may be a reduction-gear, an electric drive or a hydraulic transformer, but it is sure to come into use and rather soon.

With regard to the engines, I believe that all single-acting internal-combustion engines for marine work, from the largest Diesel to the smallest gasoline outfit, should have the base closed in almost air-tight, and that a part

Digitized by Google

of the air supply to the carbureter should be taken from the base. The open-column construction is excellent if well closed in, but with even the best of engines some gas will blow past the pistons, and smoke from the oil on the walls and on the under side of the piston-head will fill the base, and unless this is closed in and ventilated through the carbureter, will get into the engine-room.

The air starting and reversing six-cylinder engine directly connected to the propeller has had many tests, but never one as severe as in the English and American chasers. It is an unqualified success. It is a most satisfactory solution of the starting problem and entirely eliminates the reverse gear, which becomes a cumbersome mechanism in large, heavy-duty engines.

POSSIBLE EFFECT OF AIRCRAFT ENGINE DEVELOPMENT ON AUTOMOBILE PRACTICE

By Henry M Crane[1]

DURING the war a large amount of development work was done on various types of engines suitable for use in aircraft. It is only natural to speculate as to what effect the knowledge thus gained will have on the design of automobiles. A close study of the development in aircraft engines leads the author to believe that there is no reason to expect any radical change in automobile engine design. Nearly every feature of design in the aircraft engines used during the war has been used in automobiles.

One line of development which has a very direct bearing on automobile engine design was just coming to the front at the end of the war, and that was the production of composite fuels. Another thing that will no doubt have effect on the future automobile engine design is the question of materials. The advance in aircraft engines can be attributed to a more general knowledge of materials already in use before the war, which was due to greater care and better methods than to any new invention. We will in the future have a continuous and beneficial interchange of information and ideas between the two lines of engineering, but

[1]Vice-president and chief engineer, Wright-Martin Aircraft Corporation, New Brunswick, N. J.

Digitized by Google

the lines of design will also draw rather widely apart, on account of the very different problems met in the two services.

During the four and one-half years of the great war, an enormous amount of development work has been done on various types of engines suitable for use in aircraft. Many of the ablest engineers have given their whole time to this work, while practically every engineer with any knowledge of internal-combustion engines has given the various problems involved more or less thought. It is only natural, now that peace has come, to speculate as to what effect the knowledge thus gained will have on the design of motor cars. Possibly if we will consider the various engines of different types that have proved themselves in the war, it will help us in arriving at a conclusion.

These engines may be classed roughly as follows:

Radial air-cooled with rotating cylinders, such as the Gnome, Le Rhone, Clerget and Oberursel

Radial air-cooled with fixed cylinders, such as the Anzani and A. B. C.

Radial water-cooled with fixed cylinders, such as the Salmsom

Six-cylinder vertical water-cooled, such as the Mercedes, Benz, Austrian Daimler, Maybach, S. P. A., Fiat, Isotta Fraschini, Lorraine-Dietrich, Liberty and B. H. P.

Eight-cylinder V-type, water-cooled, such as the Hispano-Suiza, Liberty and Sunbeam

Eight-cylinder V-type, air-cooled, such as the Renault

Twelve-cylinder V-type, such as the Liberty, Rolls-Royce, Fiat, Renault and Lorraine-Dietrich

The V-Type Engines

The V-type engines mentioned above are those comprising two rows of cylinders. There have been a number built, also, with more than two rows of cylinders, but none of them has come into any considerable use, and in any case it is difficult to see how they would have any bearing on motor car practice. There have also been several engines having eight cylinders in a row, such as the Mercedes and Bugatti, but these do not seem to be interesting to the motor car engineers.

If we look at aviation engine design, as represented above, from a general point of view, there are several interesting features of considerable prominence that are practically standard at the present time. These features

Digitized by Google

are the four-stroke cycle, the use of valves in the cylinder-heads and the use of more or less complete force-feed oiling. I do not want to be understood as saying that engines not embodying these features have no great possibilities. I have limited myself in this case to the engines that have actually proved themselves in service.

I think it is fairly obvious why the apparent standardization has taken place on the lines described. There is no question that the four-stroke cycle poppet-valve engine, with valves in the head, is the lightest for its horsepower that has yet been developed into commercial use. The valve-in-the-head type, using poppet valves, has the simplicity, compactness and light weight of individual parts, which make up a light total weight. The four-stroke cycle, due to positive charging and efficient scavenging, allows very high speeds, and therefore high powers for a given size cylinder, as well as excellent fuel economy. The constantly increasing speed of airplanes and the development of geared engines have made it possible to take full advantage of these characteristics.

The use of force-feed oiling has naturally come to the front, in view of its positive action, and because the oil circulation is of great assistance in cooling parts of the engine that would not otherwise be properly cooled.

Of course, we know that the important feature in an airplane engine is reliability of operation, together with the lightest possible weight for a given power, the weight necessarily being taken as that of the whole powerplant, including all cooling accessories, fuel, oil and the necessary tanks for the length of flight required. On the other hand, long life, durability and ease of repair, while they have received a great deal of thought, have naturally been of much less importance than usual, because of military considerations. Aerial warfare is more or less an informal racing proposition without any particular rules, and with the life of the pilot frequently paying for defeat. The question of first cost and the cost of maintenance, therefore, cannot be given the same consideration as in the more commercial motor car field.

It is the striving for light weight and compactness that has resulted in the various radial engines, as well as the V-type engines. It has also resulted in the development of improved forms of cylinder construction, this being a point where the greatest weight saving could be made, cast-iron cylinders due to the inherent weakness

Digitized by Google

of material and methods of fabrication being extremely heavy in proportion to the work performed. The steel cylinder has become almost universal in military engines for these reasons, being formed with radiating fins in air-cooled engines and provided with suitable water-jackets in water-cooled engines.

Water-Cooled Engines

In the water-cooled engines, two pretty definite types of construction have come to the front. The Mercedes type, in which a complete cylinder unit, including the water-jackets, valve-ports and other fittings, is made up of various parts, all of steel, in most readily machinable forms, these parts being welded together. A very large number of successful engines, including our own Liberty engine, have been constructed in this way. The second system first came into large and successful use in the Hispano-Suiza engines. In this system, the cylinder wearing surfaces are of steel, while the water-jackets, valve-ports and other parts are cast aluminum. A number of interesting modifications of the Hispano-Suiza design have recently been proposed and some of them undoubtedly will prove to be successful.

It might at this point be interesting to the members to hear that we have recently completed an engine similar to the 300-hp. Hispano-Suiza, the only difference being in the use of a steel cylinder construction, and that the weight of the two engines proved to be almost identical, the one with steel cylinders being slightly heavier dry than the one using the aluminum casting construction, but the weight with the jackets filled with water is almost identical because of the smaller amount of water carried in the steel-cylinder unit.

There has been a steadily increasing use of aluminum-alloy pistons in aviation service, partly due to the light weight, but more because of the very much improved cooling due to the high heat conductivity of this material.

Of course, crankshafts, crankcases, bearings, etc., are considerably lighter for the horsepower developed in aviation engines than in pre-war automobile designs. We must remember, however, that aircraft engines are not subjected to external shocks and vibrations to anything like the extent that automobile engines are, and, furthermore, that quietness of operation can be absolutely disregarded. If we add to these facts the point already stated, that durability, ease of manufacture and of repair

Digitized by Google

have been sacrificed to a considerable extent to the saving of weight, we can reach a more just estimate as to the possible value of such improvements in future automobile designs.

A factor contributing to the lowering of the power-weight ratio has been the ability reached to maintain very high mean effective pressure in large-size cylinders. A number of very light engines are successfully developing 45 hp. per cylinder and are able to maintain this power for hours at a time. Mean effective pressures as high as 130 lb. are being maintained in cylinders having piston displacements of 140 cu. in., with compression ratios of 5.35 to 1.

There are two other things which have assisted in lightening engines, these being greatly increased power, which means that planes no longer need to be operated continuously with wide-open throttle, and that much of the flying is being done at considerable altitudes. This latter feature has a very marked effect on the reliability and life of all aircraft engines. Various schemes have been tried out with the view of obviating loss of power with attitude in aircraft engines, but naturally such devices have no practical bearing on automobile work.

Another line of development which has a very direct bearing on automobile engine design was just coming to the front at the end of the war. This is the production of composite fuels. The admixture of one part benzol with four of gasoline raises the ignition temperature of the mixture to practically that of benzol. This allows of increasing compression ratios far beyond anything that is feasible with gasoline alone. While this is of undoubted value in connection with the very high-grade gasoline used for military aviation, it has a far greater interest in connection with the very much less volatile gasoline used daily in automobiles. The temperature at which gasoline ignites becomes lower and lower as less and less volatile grades are used. While we can look forward very hopefully to the effect of this new fuel development in automobile work, we must not forget that it does not solve the questions of vaporization and distribution, which are always present in using gasoline having a high boiling point.

Use of Improved Materials

Regarding the question of materials, the recent advance in aircraft engines can, I think, be attributed

Digitized by Google

almost entirely to a more general knowledge of materials already in use before the war. Very much higher grade aluminum castings are required than were commercially possible several years ago. Improvement came rapidly with the increasing Government demands, but it was due to greater care and better methods rather than to any new inventions.

The same situation holds good with regard to the various steels required. In the Hispano-Suiza engine we are using exactly the same steels we have used in motor cars for the last 10 yr., with the exception of exhaust-valve material. The use of steel having a chromium content of 12 per cent has, because of its non-oxidizing properties at high temperatures, been very satisfactory in exhaust valves. The Liberty engine also requires no fancy materials for its successful operation. The main thing is that information regarding the manufacture, heat-treating and testing of alloy steels is much more widely distributed than before. Personally I have learned that the fabrication of the steel to be employed is far more important than the analysis. For example, a carelessly manufactured chrome-nickel steel is a snare and a delusion. I have often felt like building one Hispano-Suiza engine using nothing but straight carbon steel throughout, provided I could get such steel fabricated with the care used in making alloy steels. I have very little doubt that such an engine would stand up in direct comparison with our regular product.

There is another point of vital importance in aircraft engines, and that is the main and connecting-rod bearings, especially the latter. I think that we have learned a great deal about making babbitt-lined bearings with bronze or steel backs since the war started, but we have been able to get excellent results with the same grades of babbitt and bronze as were used before the war, improvements being made in the method of fabrication. We have run our 300-hp. engine for hours at a time, taking from 75 to 85 hp. out of it per crankpin. Each of these bearings is about 2½ in. long, disregarding fillets, and 2⅛ in. in diameter. These engines, when run at sea level, preignite practically all the time, the best power being obtained in this manner.

We have come to the use of a rather heavy bronze back babbitt-lined bearing for this work, with sufficient oil circulation not only for lubrication but also for cooling.

Digitized by Google

The smaller Hispano-Suiza engine, as well as all the engines that I have ever designed, had very energetic circulation, being far beyond immediate lubrication requirements. When the 300-hp. type was being developed the oil consumption ran very high in the early samples, and there was a suggestion from the other side to remedy this by reducing the oil flow through the crankshaft. We believed this to be a mistake, and that no such action would be necessary with proper cylinder and piston design, and this proved to be the case. With the best that we can do, in lubrication and cooling, however, unless there is a 100 per cent bond between babbitt and bronze, the bearings will not stand up, the babbitt cracking and flaking off after longer or shorter periods of operation. From our own experience we have concluded that all efforts to hold the babbitt mechanically, as by the use of holes, dovetails or screw threads, for example, accomplish no good purpose, the trouble with most of them being that they are more or less local, and also that they make rapid variations from point to point in the cross-section of the babbitt. The screw-thread system possibly has not these defects, but it has two others; first—the difficulty of getting absolute cleanliness, and second—the probability of entraining air when pouring the babbitt. After all is said and done, the one sure method consists of absolute cleanliness. If the bronze is unoxidized and the tinning is maintained in an absolutely unoxidized condition until the babbitt is poured, nothing else is required to make a thoroughly satisfactory job.

Ignition

We must not overlook in this discussion the question of ignition. With detailed improvements in engine construction, higher and higher compressions have been successfully used and necessarily higher and higher explosion temperatures. In modern aviation engines, spark-plugs which will run successfully in automobiles for thousands of miles without attention fail in 5 min. of full-load operation. The spark-plug is a study in itself, being a beautiful compromise between running so cold that it will become fouled with oil and running so hot that it will cause preignition, or that its insulating properties will break down, causing delayed ignition or misfiring. Tremendous advances have been made in the quality of insulating material and in the detailed design

Digitized by Google

of plugs, which will undoubtedly have a tendency to improve the product for automobile uses.

The effect of steady high-speed running with accompanying shocks and vibration on magnetos, especially of the eight and twelve-cylinder types, has forced a very great improvement in detail manufacture in this line. It is unbelievable that it will not have its effect on subsequent commercial manufacture. I think this is equally true of the battery ignition systems, which have come into successful use on aircraft engines during the war.

Because of the very high operating pressures and temperatures, valve or piston leakage in aircraft engines becomes a most serious matter. No new inventions in piston rings have been required to meet this condition, but simply a higher grade of fabrication on already standard lines.

In the accessory field, the design of radiators has been given a new impetus. In many motor cars the radiator, due to different features of design, is larger than is absolutely necessary and the most efficient types of cores have not been required. I feel sure, however, that the new types developed for aircraft work, such as the single hexagon tube construction, will prove to be very useful in automobile work.

Radical Changes in Design Unlikely

Looking back over the facts brought to your attention in this paper, I feel certain you will agree with me that there is no reason to expect any radical change in automobile design, due to aircraft engine development. Nearly every feature of design that I have described has been used in motor cars. For instance, an eight-cylinder V-type engined car was actually produced by E. R. Hewitt in 1908, following the idea first put into service in the Antoinette aviation engine. I do expect to see an increase in the number of valve-in-the-head engines, due in part to the general efficiency of this arrangement, but more especially to the fact that this construction lends itself extremely well to the separable cylinder head, which is coming into continually greater and greater use. We have already seen a number of successful engines with cast-aluminum block-cylinder construction and this development may be expected to continue.

I have purposely based my consideration of this subject on the commercial use of motor cars for passenger and freight service. In racing cars, of course, the effect

Digitized by Google

of aviation engine progress is bound to be extremely marked, as the service required is very similar in the two cases. In commercial motor car work, however, the percentage of the total loaded weight which can be saved by detail lightening of the engine is not very great, and this saving is apt, as I have pointed out, to be at the expense of durability and ease of construction and repair.

Furthermore, in my opinion the motor car engine should be designed to develop its best pulling characteristics at considerably lower speeds than does the aircraft engine, which will undoubtedly mean very much lower compression ratios and lower mean effective pressures..

To sum up, I think that we shall in the future have a continual and beneficial interchange of information and ideas between the two lines of engineering, but I think, also, that the lines of design will draw rather widely apart, due to the very different problems to be met in the two classes of service. [The discussion of this paper will be found at the conclusion of O. E. Hunt's paper on page 161.]

Digitized by Google

A COMPARISON OF AIRPLANE AND AUTOMOBILE ENGINES

By Howard C Marmon[1]

ANY aggregation of parts assembled to obtain a mechanical result is a series of compromises. The relative importance of the objectives governs the nature of the compromise. The major objectives to be considered in the design of airplane engines are

(1) Reliability
(2) Small weight per horsepower
(3) Economy of fuel and oil consumption
(4) Carburetion that permits of easy starting; maximum power through a range of 30 per cent of the speed range; and idling at one-quarter maximum speed without danger of stalling
(5) Ability to deliver full power through a small speed range without excessive vibration
(6) Complete local cylinder-cooling under conditions of high mean effective pressure
(7) Compactness

The automobile engine must have

(1) Reliability
(2) Silence
(3) Carburetion that accomplishes proper and even firing in all cylinders under varying throttle conditions, through speeds covering more than 90 per cent of the speed range of the engine. Great flexibility, with economy secondary
(4) Ability to deliver partial or full torque through its entire range of speed without vibration
(5) Compactness
(6) Small weight per horsepower

Starting from these basic qualities, the author makes a close comparison of construction, methods of use, adaptations and elimination of parts, weights and fuels. The question of design of crankshafts and crank cases is discussed. The action of an airplane engine in an automobile and the changes needed to insure success are specified. The conclusion is reached that none of the major features of the airplane engine can be grafted directly upon the automobile. The auto-

[1]Vice-president, Nordyke & Marmon Co., Indianapolis, Ind.

Digitized by Google

mobile will be improved as a result of airplane experience, but this improvement will be evident in the service the automobile gives, rather than in radical changes of design.

In physical construction the four-stroke cycle airplane and the automobile engine are identical. From the delivery of the fuel to the carbureter to the delivery of the power generated at the crankshaft end, the processes are the same. An automobile engine could be made to fly an airplane, and an airplane engine or a replica of it on a reduced scale to bring the power within usable limits, could be employed to operate an automobile. A long series of disappointments has emphasized to all of us the fact that any aggregation of parts assembled to obtain a mechanical result is a series of compromises, and the relative importance of the objectives governs the nature of the compromise.

Controlling Factors in Design

The major objectives that govern the compromises to be made in the design of airplane or automobile engines are roughly as follows in approximate relative importance. We are considering the airplane engines that have been developed for use in warfare. They must have

(1) Reliability
(2) Small weight per horsepower
(3) Economy in fuel and oil consumption
(4) Carburetion that permits easy starting and maximum power through a range of 30 per cent of the speed range, and idling at one-quarter maximum speed without danger of stalling. In short, no great degree of flexibility is required
(5) Ability to deliver full power through a small speed range without excessive vibration
(6) Complete local cylinder cooling under conditions of high mean effective pressure
(7) Compactness

In general, it can be assumed that the airplane engine will receive expert attention daily; it will be operated on a homogenous highly volatile fuel and be lubricated with good oils. Relatively little regard need be given to the expense involved in fabricating any part of the engine or in the original tooling-up. Further, a comparatively small part of its life will be spent at sea level and none in a dust-laden atmosphere.

Digitized by Google

The automobile engine must have

(1) Reliability
(2) Silence
(3) Carburetion that accomplishes proper and even firing in all cylinders under varying throttle conditions, through speeds covering more than 90 per of the speed range of the engine. In short, great flexibility. Economy is secondary to this requirement
(4) Ability to deliver partial or full torque through its entire range of speed without vibration
(5) Compactness
(6) Small weight per horsepower

In general, it can be assumed that the automobile engine will receive attention at infrequent intervals and then usually at the hands of an inexpert person. It will be operated on fuels of low volatility and lacking in uniformity, and varying grades of lubricating oils will be used. The cost of fabricating the parts and tooling-up must be kept in mind. Further, the engine must be designed to operate at higher speeds than is customary in airplane engines. Its entire operation is likely to be near sea level and often in a dust-laden atmosphere.

Reliability has been given as a prime requisite for both types of engine. It should be remembered that an automobile which has traveled 10,000 miles has had its engine running from 300 to 500 hr. This is considerably in excess of the normal life of an airplane engine in warfare. A typical two-seated airplane loaded with all its paraphernalia for reconnaissance work and the incidental fighting would, as it left the ground, have 20 per cent of its weight represented by bare engine and 15 per cent by fuel for a 3 or 4 hr. flight. These figures represent the extreme that has been attained in lowering the power-weight ratio and in fuel economy. A typical automobile carrying five passengers and fuel for an 8 or 10 hr. run would have, not including flywheel, clutch and starter, less than 10 per cent of its weight in the engine and 3 per cent in fuel.

In obtaining the greatest power output per pound of weight, it is necessary to get the greatest power output per cubic inch of piston displacement. In the airplane engine the most successful solution has resulted from the use of a compact combustion chamber, valves of ample size, large passages in the intake manifolds, carbureters designed especially for the engine speeds

Digitized by Google

contemplated, and the highest practical compression pressures, bearing in mind that a fuel of high volatility is to be used and much of the operation is to be at reduced barometric pressures.

The automobile engine will not equal the airplane engine in power per cubic inch piston displacement, as it must be carbureted for greater flexibility and not solely for maximum torque output through a comparatively limited range of speed. Two to four carbureters, which are usual on multi-cylinder airplane engines and add to their maximum output, would not be welcomed on the automobile.

Nor can the automobile engine use a compression pressure as high as that of the airplane engine, which means that its power for a given displacement, output and fuel economy must be lower. The high compression pressures would be impracticable at the full load and low engine speeds required of the automobile engine, but not of the airplane engine.

The lower grade fuels commonly used in automobile engines are more troublesome under high compressions than the fuels customarily used in airplanes. It should also be remembered that the higher the compression ratio it is possible to use at ground level in an airplane the better the engine functions at altitude. At an elevation of about 15,000 ft. the compression pressure is reduced about 40 per cent.

Compact combustion chambers make valves in the head necessary. Mechanically the most efficient way yet devised to actuate these valves is by overhead camshaft and the use of abrupt cams. The gear train for operating the overhead camshaft from the crankshaft is rather complex and expensive, but by using proper materials can be made very light and durable.

Reduced Weight in Cylinder Construction

The greatest weight reduction in cylinder construction seems to be obtained in the steel cylinders with welded-on jackets, usually individual. All-steel cylinders are available only for valve-in-the-head engines. Steel cylinders have a particular advantage in that it is possible to get cooling water close to the interior walls of the combustion chamber and to the valve seats. This is of considerable help in connection with high mean effective pressures and tends to reduce carbonization. Steel cylinder walls can be made so thin that they will

Digitized by Google

permit the bore of the cylinder to increase 0.010 to 0.012 in. during the explosion stroke without affecting the power output.

If the steel cylinder is the lightest and lends itself readily to the most effective way of producing power for a given displacement, why should it not be adopted for automobile use? For passenger car use its comparatively excessive cost is the least of the objections. *Per se*, the steel cylinder wall offers no advantages over cast iron. In European aviation practice, notably in air-cooled engines, steel cylinders have been lined with cast-iron sleeves about 1/32 in. thick. In its best development, for ease of manufacture, least amount of water weight, and the best circulating water distribution, the steel cylinder is of the individual type. Individual cylinders in a passenger automobile are not desirable because of the increased over-all length consequent upon such a design, the multiplicity of water, gas and exhaust connections and valves in the head. With steel cylinders, valves in the head may be operated by push-rods from a camshaft in the crankcase, as in the Benz aviation engine, but for automobiles the problems of enclosure against dust and proper lubrication of parts present difficulties that are not easily solved.

An attempt to operate the valves of a passenger automobile with the overhead camshaft would not be likely to succeed commercially. Not only would its comparative complexity over other methods of valve operation producing excellent results be against it, but, what is more important, no durable way of driving an overhead camshaft and all the accessories required on an automobile has yet been devised. It seems to be fundamental that a passenger car engine must operate with a total amount of noise that is, at the most, unobtrusive.

In addition to this, the cylinder walls would have to be thickened to a point where no spring from the explosion pressures would result in that constant source of trouble to the manufacturer, piston slaps. Some of the weight advantages would diminish with this change.

One of the greatest contributions to our knowledge of engine manufacture resulting from airplane engine production is the steel cylinder, and, strangely enough, probably the greatest application of steel cylinders will be on the large truck or the tractor engine. Here the noise is less important, as is also the fore-and-aft bulk. The unusual cooling advantages offered by the steel cylin-

Digitized by Google

der make it particularly suitable for heavy duty under the unfavorable conditions often required of the truck or tractor. The small relative mass of such cylinders is conducive to their staying in place without the loosening or fracture due to the excessive vibrations often encountered in such cases from causes other than engine operation.

Design of Crankshafts and Crankcases

In the design of an airplane engine crankshaft, the need of minimum weight per horsepower will govern. A material of high specific strength will be used, and empirical data will be employed in the design to avoid periodic vibrations in the narrow speed zones in which the engine operates. In the layout of the automobile crankshaft, it must be remembered that all periodic vibrations must be avoided from the lowest speed to speeds higher than those employed in the airplane engine. This results in designing for a certain stiffness, which would enable the use of material relatively inferior but still having sufficient strength. Hence the requirement of smooth operation under a greater variety of conditions makes it impossible to meet, in the automobile engine, the low weight factors of the airplane engine.

What may be termed the tubular type of crankcase is the lightest on a power-weight basis and presents the greatest opportunity for heat dispersion from bearings of any crankcase design yet offered, and is widely used in airplane engines. It is split on its horizontal axis, the upper portion carries one-half the crankshaft bearings and the lower portion the other half, and the two halves are bolted together with bolts going entirely through the case. The conventional automobile design, in which the upper half of the crankcase, plus whatever bridgework reinforcement the cylinders offer, carries the entire crankshaft load, the lower half being merely an oil container, is quite appreciably heavier. It will, however, in all probability be retained for automobile work on account of its greater accessibility and the greater ease with which corrections for wear can be made.

Total bearing loads and the effect of parts that apply these bearing loads will be greater in automobile than in airplane engines, as higher engine speeds must be provided for. The forces due to reciprocation of parts become greater in proportion to the horsepower output than in the airplane engine. The factor V^2 of the MV^2

Digitized by Google

equation increases more rapidly than the factor M can be reduced.

Higher mechanical efficiencies with their correspondingly greater horsepower output per cubic inch will be obtained from the airplane engine than from the automobile engine. The easy clearances on the pistons, the ample freedom given all the bearings, the gear trains, etc., that mark the assembly of the airplane engine produce a machine that responds and is ready for the hardest duty at the moment it is first fired. Give the automobile engine this same mechanical freedom, and one of the prime requirements of automobile engines, silence, will be so lacking that the engine would be promptly condemned.

The need for economy of fuel and oil has been emphasized. It appears that any fairly conventional water-cooled engine with a reasonably compact combustion chamber with cylinders sufficiently well cooled locally to permit good compression pressures, can reach ½ lb. of fuel per b.hp.-hr. over the speed and power ranges required. Over equivalent ranges, with proper allowances made for reduced compression ratios, automobile engines will compare very favorably. However, the requirements of great flexibility, sudden demands for idling, quick acceleration in crowded traffic conditions, present economy problems for which airplane engine history provides no parallel.

While the steel-cylindered airplane engine has been considered principally, it is not intended to overlook the well-known aluminum-jacket engines and the Bugatti extraordinarily clever design using all cast iron above the crankcase, which engines produce much the same results when installed in an airplane. They have one advantage for automobile use not possessed by the steel-cylinder engine, more complete enclosure of valve operating parts. However, an analysis of all of them will show that the objectives aimed at have necessitated compromises as do other constructions.

An Airplane Engine in an Automobile

Let us now see what happens if we take any four, six, eight or twelve-cylinder aviation engine and make a faithful replica of it on a reduced scale so that its power output fits the needs of the particular car we wish to try it in. The engine will be heavier per horsepower than its prototype; cylinder walls will be as thick; crankcase

Digitized by Google

walls will be as thick, as undoubtedly foundry practice dictated the thickness of the larger one; ignition, spark-plugs, float chamber and many similar parts will weigh as much per cylinder as in the larger engine. The weights in pounds per horsepower will show a considerable increase. However, when installed in the car, and with the usual flywheel, clutch, starting and lighting systems, tire pump and so on added, it will weigh from one-half to two-thirds as much as engines employed in our usual practice.

A trial of the car so equipped will show some extraordinary performances in speed and hill climbing when the original start for the hill is rapid. City driving under traffic conditions or heavy pulling at low speeds will demand a new carbureter and intake system to meet these conditions. This will seriously affect the conditions that made the first impressive performance. When satisfactory control of the engine has been established, noises demand attention. A general snugging up of parts helps, but a few noises remain that it is finally decided can be corrected only by a redesign, probably of the valve operating gear. All this affects the original performance adversely. After this has been done, certain conditions of operation will require an enlargement and stiffening of the crankshaft to eliminate an annoying periodic vibration. The result is an engine not a great deal lighter or more efficient than the one originally designed for the car.

The airplane engine is a more expertly engineered and better manufactured development of the internal-combustion engine than the automobile engine. It is, however, developed for a set of objectives different from those demanded in an automobile, and none of its major features can be directly grafted upon the motorcar. It is true that a multitude of engineering minutiae have been developed that are applicable to the motorcar, but the total result in operating performance is small.

The greatest contribution from the airplane engine to the motorcar industry has come through the builder of the engines. He has shown that, given a definite set of specifications and a definite request for results, engines will leave his factory with absolute assurance as to what they can do. Some of the optimists have suspected this, but the war's aviation engine experience has proved it.

Motorcars will be improved as a result of our airplane

Digitized by Google

experience, but this improvement will be apparent in the service the car gives, rather than in any radical changes in design. This will come about as a result of better manufacturing facilities, higher shop standards and more intelligent inspection. [The discussion of this paper will be found at the conclusion of O. E. Hunt's paper, on page 161.]

PROBABLE EFFECT ON AUTOMOBILE DESIGN OF EXPERIENCE WITH WAR AIRPLANES

By O E Hunt[1]

THE impression that recent aircraft experience should have taught engineers how to revolutionize automobile construction and performance, is not warranted by the facts involved. Aircraft and automobiles both embody powerplants, transmission mechanisms, running gear, bodies and controls, but their functions are entirely different. The controls of an airplane, except in work on the ground, act upon a gas, whereas with an automobile the resistant medium is a relatively solid surface. Similarly, the prime function of the fuselage is strength, weight considerations resulting in paying scant attention to comfort and convenience, which are the first requirements of an automobile body. Aircraft running-gear is designed for landing on special fields, and is not in use the major portion of the time. The running-gear is the backbone of an automobile, in use continuously for support, propulsion and steering; hence its utterly different design. In an airplane the transmission system does not require variable ratios, is rigidly aligned and covers only short distances, so that the automobile can borrow little from it.

While much of the information acquired in aircraft work will undoubtedly be beneficial in automobile work, it must be considerably discounted because automobile flexibility and quietness are much more important than light weight and high mean effective pressure. Probably more aluminum will be used in automobile engines as commercial conditions permit, but wholesale adoptions of all-steel cylinders, sections machined to utmost lightness, etc., are prohibited at present by first-cost

[1]Chief engineer, carriage division, Packard Motor Car Co., Detroit, Mich.

Digitized by Google

considerations. Most of the extreme methods of raising horsepower per pound are barred in automobiles on account of noise or their effect on flexibility.

Summarizing it is believed that the chief advantage derived from aircraft experience, aside from comparatively minor points, will be the tendencies of engineers to seek lighter weights at a cost within reason, better metallurgical results, better workmanship, and the like. In other words, the benefit will be from inspiration rather than from design details.

There seems to be an impression in some quarters that the aircraft experience of the last two years should have taught engineers how to revolutionize car construction and performance. The facts appear to offer no real foundation for such an opinion.

In general, cars and airplanes can be divided into the same design elements. They both have powerplants, systems for the transmission of power from the engine to the point of its absorption, running gear, bodies and controls. Let us take each of these elements and compare its design and the conditions surrounding its use in both types of service to determine whether the development of the element in the one service will automatically tend to produce a similar development in the other.

Control and Body Differences

Controls in both cases have to cover the functions of steering and changing speed. In the case of the plane, the steering function is performed by ailerons, elevator and rudder, the first two controlled from the hand-operated stick and the last from the foot-operated rudder bar. Changing speed with relation to the ground is accomplished in the plane by changing the engine speed with the conventional spark and throttle controls, by changing the attitude of the plane in the air with the steering controls, and by taking advantage of wind currents. For instance, the reduction of speed accomplished in a car by throttling the engine, declutching and braking, would be produced in a plane by throttling the engine, increasing the angle of the planes to the direction of flight and heading into the wind. In landing, an incidental and added braking effect is obtained from the dragging tail skid. It is perfectly obvious that developments in airplane control are not going to revolutionize car control. The two systems are fundamentally different.

In the airplane, the body or fuselage performs many

Digitized by Google

more functions than in a car. Aside from seating and protecting the passengers, it is the chief structural member of the machine and carries the engine, the supplies and the useful load, which functions are performed by the chassis in the case of the car. Maximum strength with minimum weight exercises a controlling influence in the design of a fuselage, with the result that the convenience and comfort of the passengers receive but scant attention. Doors and stepboards for convenient entrance would add weight, weaken the structure, and increase wind resistance. Consequently, the passengers reach their seats by scaling the side of the machine and sliding down through an opening in the top of the body. The seat, as a rule, is scantily padded, presumably to reduce weight. The leg room is usually scant. A view of the surroundings is insured by placing the seat so that the passenger's head sticks up through the opening by which he entered. The windshield function is supposedly performed by a small piece of glass or celluloid set on top of the fuselage, just forward of the cockpit; but in my experience, goggles are the real protection. It is hard to conceive that information which would help us to improve car bodies, where comfort and convenience of passengers are prime requisites, can result from a study of fuselage construction. Due to the radical differences in design, there is little, if any, structural detail that could possibly be used in car bodies. An increased use of stamped braces and the possible use on the more expensive bodies of bent structural parts of veneer, are the only immediate possibilities for body structure suggested by a fairly intimate knowledge of airplane body design.

In a car, the chassis is the backbone of the whole structure. In a plane, it is a parasite when the machine is in the air, and is so considered in connection with plane design. Being useful only in taking off and landing and a drag on performance due to both weight and wind resistance when the plane is in the air, its bulk and weight are made as small as possible; and since, in theory at least, taking off and landing are done on specially prepared fields, the factor of safety is made much less than in the corresponding element of the car. The chassis is fundamentally simple in construction, too, because its axle exercises neither a steering nor a torque transmitting function, as in car axles. The only possible contribution to car design that could result from expe-

Digitized by Google

rience with the airplane landing gear would be the development of light wheels and tires that might some day find a place on high-grade light cars.

An airplane is almost entirely devoid of a power transmission system. The conventional airplane engine has the propeller mounted directly on the end of the crankshaft. For certain purposes, reduction gears of a fixed ratio are used to drive from the crankshaft a layshaft carrying the propeller, but gear changes, such as are applied to cars, are unknown. The only element of the power transmission that has a counterpart in car work is the propeller-hub which performs a similar function and is similar in design to the rear wheel hub of cars. Airplane propeller hubs must be readily demountable and this requirement has resulted in some new design detail that is entirely unnecessary for cars.

Airplane and Car Engine Service Conditions

But the engine, you say, is a different matter. Has not the war proved that highly developed, water-cooled, fixed-cylinder engines of the automobile type are the most dependable airplane engines at the present stage of the art; and will not the experience gained in reducing the weight and increasing the volumetric efficiency of these airplane engines be of immediate use in decreasing the weight-horsepower ratio for car engines? This may help in a limited way but not nearly to the extent some engineers would have us believe, because, in spite of similarities in design, the engine requirements for airplane service are so far different from those for cars that factors which are vital in the former type of machine are of minor importance in the latter and vice versa. In an airplane engine dependability, light weight, high mean effective pressure, excellent economy, first cost, flexibility and quietness are controlling factors in about the order listed, while in the case of the car engine the relative order of importance is almost completely reversed and would read dependability, flexibility, quietness, first cost, economy, light weight and high mean effective pressure. Exception may be taken to the order given for cars, particularly as regards first cost and light weight, but since probably over 90 per cent of our total car production is designed to fit a definite price class, it will be realized that first cost has a predominant place in the design councils of the industry as a whole, and that light weight is of major importance only as it results

Digitized by Google

in the reduction of the total amount of material to be purchased, thus reducing the material bill. Flexibility and reasonable quietness, like dependability, have come to be expected in all cars, and no car that does not give proper performance in these respects can hope to remain in public favor. I must confess that in placing economy below first cost I am reflecting the buyer's attitude as he, thanks to the manufacturer's reputation for never understating his case, will give greater weight to a known economy in first cost than to a promised economy in operation.

Changes in Airplane Engines Not Suitable for Cars

Airplane engine design detail that will increase dependability is immediately useful in cars provided it does not entail an abnormal increase in first cost. Airplane spark-plug development is an example. There are other minor ones that I shall not attempt to mention in detail here.

In general, light weight in airplane engines is obtained by the use of unusual light materials such as aluminum, regardless of cost, and by the reducing of all parts to the smallest section that will give a satisfactory dependability, with little regard to the labor involved in so doing. Aluminum has been generally used for oil-pumps, water-pumps, cylinders, and to a greater extent in carbureters, induction pipes and electrical equipment, than is common in car engines. A most significant example of the minimum section method of obtaining lightness is the all-steel cylinder used on the Liberty and some other airplane engines. I believe that the more extensive use of aluminum in car engines will be stimulated by this experience provided the price of this metal comes down to a point where, better machining allowed for, it can compare fairly well with cast iron in cost of the finished piece. There does not seem to be much reason to expect a landslide to light parts of the steel-cylinder variety as the cost of producing them by present methods is out of all proportion to the dividends they would pay in car service. Commercialization of the airplane engine will undoubtedly be along the lines of perfecting less expensive methods of manufacture for such parts. This may ultimately result in costs low enough to warrant their use in cars.

Many improvements contribute to high volumetric efficiency in airplane engines. Overhead values are already

Digitized by Google

used to a limited extent on car engines, but the overhead camshaft that is almost universal on airplane engines is practically unknown on cars outside the racing class because of the difficulty of getting a quiet and inexpensive form of drive. Very high compression and open exhaust are barred for car use because the former militates against flexibility and the latter is too noisy. Abnormally large valves and high lift are generally frowned upon in cars because of the tendency toward a lesser valve life and lack of quietness in operation. The unusual care taken to cool valves and spark-plugs in airplane engines in order to combine proper dependability with high efficiency usually involves structural features of the steel-cylinder type that are too expensive for cars. Abnormally large intake passages and carbureters are not usable in automobile engines because of the unsatisfactory effect on flexibility. On the whole, the engineer must be very cautious with the use in cars of design "stunts" that contribute to raising the mean effective pressure in airplane engines or he may find to his sorrow that he has sacrificed results that the public insist upon as necessary to satisfactory car performance. There seems to be no immediate promise of a general increase in the average mean effective pressure of car engines based on airplane experience.

The dead load that present-day airplanes can handle satisfactorily is relatively small. The power required to give them satisfactory performance is so high that a considerable proportion of this dead load must go to supplies, leaving only a small portion for useful load, or, if a large useful load is desired, the flight range is small. Economy of fuel is then of real importance. Good distribution, a carbureter setting as lean as will give full power over the engine speed-range ordinarily used in flight but not so lean as to accelerate valve burning, and a sensitive means of reducing the fuel flow to an amount that will give a proper mixture with the lighter air at altitude, are the design details used to accomplish it.

The distribution and mixture adjustment experience is usable on cars, but it is obvious that the high-speed lean setting would not give proper flexibility. Oil economy is of much less importance from the weight standpoint, but it is carefully watched in airplane engines and methods for producing proper results in them will be useful in car design. Accommodating the oil supply to the load, which is very essential in airplane engines,

Digitized by Google

has produced schemes for the interconnection of the throttle with the oil-pressure regulator that may find their way into cars of the higher grades.

It is a well-known fact that first cost has been largely overlooked in war airplane engine design where there was any military advantage to be gained by so doing. Such neglect obviously has not tended to produce design detail that could be used in cars, where first cost is of great importance.

Flexibility, or more particularly, speed-range at full load, is relatively unimportant in an airplane engine which operates in the upper 20 per cent of the possible range with a given propeller for at least 90 per cent of the time it is at work. Flexibility being sacrificed to economy through the remainder of the range, it is obvious that we can learn nothing from airplanes in connection with this car essential.

In airplane service the noise of the propeller and the open exhaust drown out the mechanical noises of even the least quiet engines. Until these are eliminated, and there seems to be no prospect of getting rid of the propeller noise, airplane engines will continue to rattle and "slap" in a way that would drive the average car user to distraction.

Results of Airplane Design and Construction

A summing up of all this evidence indicates that there is very little ground for assuming that airplane experience will suddenly and immediately revolutionize cars. Market conditions being right, we may see an increase in the use of aluminum. If aircraft are commercialized to an extent that demands volume production of engines, we may develop methods of making the minimum section type of lightness that will make this practice usable in cars. There may be an increased tendency toward overhead valves and camshafts if the mechanism involved can be made sufficiently inexpensive and quiet. There are possibilities of minor improvements in carburetion and oil control and in some other details.

I believe, however, that the most important contribution which the airplane has made to the automobile is the stimulus to the thought of the industry as a whole that has resulted from the study of its design and manufacturing problems. Our war experience has set engineers to dreaming of ways to produce a light-weight result at moderate expense. It has taught an increased respect

Digitized by Google

for good metallurgical practice as a necessary factor in successful design and manufacture. It has given the average manufacturer, who engaged in airplane engine building, a new conception of the value of high-grade workmanship and of the small margin of cost that, in many cases, separates it from the ordinary variety. I should say that in setting up new ideals of design and workmanship for the industry to strive toward, this study has given us an inspiration of far greater value than any design details could possibly yield.

THE DISCUSSION

J G VINCENT:—I believe the most significant thing in connection with this paper and the two immediately preceding by Messrs. Marmon and Crane is the fact that three thoroughly experienced automobile engineers who have played a leading part in aircraft development during the war have written entirely independent papers on practically the same subject without, so far as I can find, a single note of disagreement. If I had written an independent paper on this same subject I would have covered exactly the same subject matter and made exactly the same statements, so that I am naturally in agreement with all the statements of these three gentlemen. I believe that these papers are particularly well written, and I think there is very little room for discussion. I believe a careful consideration of these papers by our members will probably save a lot of trouble and unnecessary experimental expense.

Digitized by Google

HIGH-SPEED HIGH-EFFICIENCY ENGINES

By D McCall White

ENGINEERS have different ideas regarding highly efficient and moderately efficient engines, but designers dare not ignore the fact that the public requires today a small very high-speed engine, with good torque at low speeds, and capable of revolving efficiently at very high speeds. These two characteristics are difficult to attain, since in practice one is really opposed to the other. To obtain high speeds with power, the valve areas, valve parts, carbureter, etc., should not be restricted in any way, while to get a good mixture at low speed with heavy torque means a different valve-setting and more or less restricted port and valve areas, etc., to secure high gas velocities.

The author states that the fundamentals of high-speed engines are high volumetric efficiency; high compression, to aid in obtaining rapid combustion at high speeds, and light reciprocating and rotating parts, to secure high mechanical efficiency. This is followed by a close comparative study of details of design and construction. In the course of the discussion attention is given to materials and other details of general manufacturing. The application of the engine under discussion to such uses as searchlights, captive balloons, tanks and tractors, is illustrated. Many photographs and charts are used. One interesting table shows the influence of the amount of lubrication on the brake-horsepower developed by engines.

Engineers have different ideas regarding engines of high efficiency and moderately efficient engines. For very high-speed engines, the designer must not lose sight of the fact that what the public requires today is a small engine which has good torque at low speeds and is capable of revolving efficiently at very high speeds. These two points are difficult enough to attain together, as one is really opposed to the other in practice, due to the fact that to obtain high speeds with power, the valve areas, valve ports, carbureter, etc., must not be restricted in any way whatever; while, to obtain a good mixture at low speeds with heavy torque, means, first, a different valve-setting, and, second, more or less restricted port and valve areas, etc., to

[1]Vice-president, Cadillac Motor Car Co., Detroit, Mich.

Digitized by Google

give high gas velocities. If one adds to the above complications the fact that it is also required that the modern valve gear be silent, the proposition is one which calls for considerable thought and ingenuity.

Briefly stated, the fundamental of high-speed engines is as follows:

High mean effective pressures at high speeds, which depend upon: (*a*) high volumetric efficiency; (*b*) high compression to aid in obtaining rapid combustion at high speeds, and (*c*) light reciprocating and rotating parts to obtain high mechanical efficiency.

It is only a few years since engines were designed with a maximum power at 1200 to 1500 r.p.m., although some designers had the forethought to consider that it was possible to attain very high engine speeds indeed, and today this is an accomplished fact.

The high-speed, high-efficiency engine of today must be designed very carefully indeed to obtain good results, as one slip will spoil the whole design entirely. We have all lengths of stroke to bore ratios, but in my opinion the stroke-bore ratio should be between 1.5 to 1 and 1.625 to 1, because one can obtain all the power required without having a very unwieldy and heavy engine.

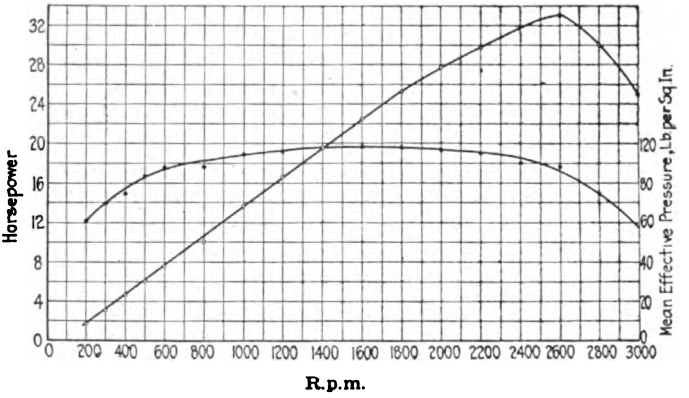
It should also be considered that there are more fastidious purchasers than ever today, and therefore there must be no doubt whatever that the engine will be practically free from vibration and most sweet, silky and silent when delivering power. In short, the saleable article, it appears to me, is the one which has small size coupled with great power and is neat and compact in design, with the requisite silence. There is nothing that pleases the owner more than this combination.

I have mentioned many times that a bore of approximately 90 mm. is about the maximum cylinder size for high-speed work, and after that I certainly believe multiplicity of cylinders should commence.

Mean Effective Pressures

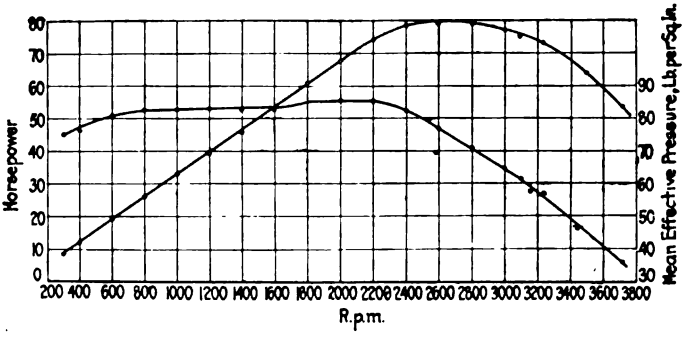
In my opinion it is quite useless to think of designing an engine to cope with the present-day market unless it can develop power up to from 2500 to 3500 r.p.m. or over, smoothly and quietly. The power must be good and a touring car engine of today must be capable of carrying a mean effective pressure of from 80 to 100 lb. per sq. in. relative to the brake horsepower, up to 2200 r.p.m.

Digitized by Google



BRAKE HORSEPOWER AND MEAN EFFECTIVE PRESSURE CURVES FOR A FOUR-CYLINDER ENGINE HAVING AN L-HEAD EXHAUST VALVE WITH A SINGLE INTAKE VALVE DIRECTLY ABOVE

at least. A power and mean effective pressure curve of a 12-hp. Napier engine designed in 1911, having one L-head exhaust valve and one overhead intake valve immediately above, might be of interest. This engine was a four-cylinder, 2 11/16-in. bore by 5-in. stroke, and showed a mean effective pressure relative to the brake of 98 lb. per sq. in. at 1400 to 1800 r.p.m. and a maximum of 33 b.hp. at 2600 r.p.m. It was fitted with a muffler but naturally pulled more power without the muffler. It had a two-jet carbureter of my own design. The crankshaft had two bearings and forced lubrication throughout. A mean effective pressure and power curve of the



BRAKE HORSEPOWER AND MEAN EFFECTIVE PRESSURE CURVES OF AN EIGHT-CYLINDER PASSENGER CAR ENGINE

Digitized by Google

standard Cadillac eight-cylinder engine, run up to the very high speed of 3750 r.p.m., is of considerable interest.

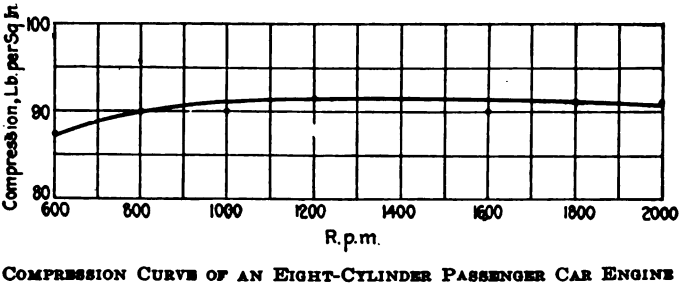
The accompanying table shows the bore and stroke of seven different engines with the revolutions per minute

Bore, mm.	Stroke, mm.	Speed r.p.m.	Mean effective pressure, lb. per sq. in.
68.0	127	2,400	89.0
68.0	127	2,000	97.5
82.5	127	1,200	82.5
89.0	127	1,200	79.5
96.0	130	1,200	127.0
80.0	130	3,000	103.0
80.0	130	2,400	104.0

and mean effective pressure relative to the brake, which I obtained from them some few years ago.

Volumetric Efficiency

To design a successful high-speed engine, it is desirable that the compression should be fairly high in order to get rapid combustion at high speeds; the clearance space should approximate 21 per cent of the total volume. A compression curve of the Cadillac eight-cyl-



Compression Curve of an Eight-Cylinder Passenger Car Engine

inder engine will be of interest as showing how the compression pressure is maintained at over 90 lb. from 800 to 2000 r.p.m.

A very simple and easy method of measuring the compression pressure, as well as the maximum pressure in an engine cylinder, is by the use of the Okill indicator, an English instrument which we have found to be very satisfactory.

Digitized by Google

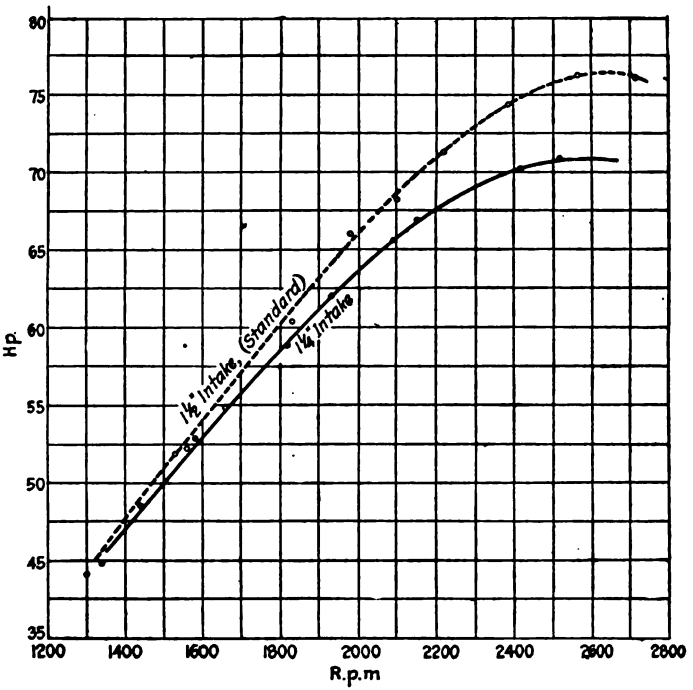
The high-speed engine might be likened to an air compressor, as the great point is to get the charge into the cylinders and thus obtain the highest possible volumetric efficiency. Much can be accomplished by considering the shape and smoothness of the pipes, eliminating bends and elbows, and particularly careful design of valve ports, seats, etc., and their cooling. As is well known, the volumetric efficiency is entirely dependent upon port area, large carbureters, large valves, etc., but coupled with these advantages is the obvious difficulty of securing proper carburetion and of starting in cold weather, the former affecting the acceleration to a very great degree. As cold weather occurs every year, it is highly important that precautions be taken by designers so that their enthusiasm for maximum power does not overstep the bounds of proper carbureter size, etc., in order to get a combination of highly satisfactory running both summer and winter.

Much has been done in heating intake manifolds, and I propose to deal with this point later. The difference on a Cadillac eight-cylinder engine in 1915, when using a 1¼-in. as against a 1½-in. intake manifold, is brought out in one of the curves reproduced. It will be noted that the power is increased right up the line from 1200 r.p.m. and is about the same at lower speeds.

Multiple Intake Valves

Regarding high volumetric efficiency, we have heard a great deal on the question of multiple valves. I do not know whether it is generally known that a group of three intake valves was used in the English Napier car in 1909. If I remember correctly, this feature was described in *The Autocar* about that time. Much has been heard of the overhead valve, and many types of overhead valve systems have been used. We have seen racing cars with overhead camshafts driven by bevel, spur or spiral gears, etc., and other valve systems with the camshaft below and push-rods with rockers operating the valves above, but I do not believe that it is possible to design a satisfactory and quiet overhead valve mechanism with a combination of rocker-arms and overhead camshafts, because of the difficulty in obtaining quiet engines. On the other hand, we have a quieter system with the camshaft below and push-rods coupled with rocker-arms operating the valves above, but I believe that the inertia of this valve mechanism would be so great as to

Digitized by Google



INCREASED POWER DEVELOPED BY AN EIGHT-CYLINDER PASSENGER CAR ENGINE WHEN EQUIPPED WITH A LARGER INTAKE MANIFOLD

almost debar it as the kind of valve gear that should be designed for a high-speed engine.

VALVE GEAR TYPES

When all is said and done, there is a great deal to be said for the L-head type of engine, because the valve gear can be kept down very light indeed, very good sized valves can be used, and it is a fact that this, up until the moment, is the quietest type of valve gear which can be used in the touring car engine. It is true that the engine fitted with overhead valves when properly designed should pass approximately 25 per cent more gas than the L-head engine, although a well designed L-head engine uses about 75 per cent of the circumference of the valve, while with the T-head engine only about 50 per cent of the circumference of the valve is effective. Where multiple valves are used, it is very easy to see by simple calculation that the frictional resistance offered by double

Digitized by Google

valves and ports is approximately 30 to 35 per cent greater than that of a single valve and port of the same area.

On the question of the inertia of valve mechanism generally, in the Cadillac eight-cylinder high-speed engine of today we are obtaining engine speeds on the road of well over 300 r.p.m. and have records of 3550 and 3850 r.p.m. road performance. If one considers that at 3000 r.p.m. the time taken to open and close one of the valves is 0.0125 sec. at 3550 r.p.m. 0.0106 sec., and 3850 r.p.m. 0.0098 sec., one sees that in a very high-speed engine the time allowed for a valve to open and close is extremely short.

At various times there have been discussions regarding the different angles for valve seats, and if one takes a seat of 50-deg. angle having a supposed lift of ¼ in., this will give a valve area across the narrowest portion of only 72 per cent of ¼ in.; while, if the valve seat having the same width of seat as the 50-deg. seat is 30 deg., this gives 87.5 per cent of ¼ in.; while the 30-deg. seat narrowed down to around 1/16 in. gives the same amount of ¼ in., but, of course, gives a larger valve bore, thus decreasing the velocity through the bore itself.

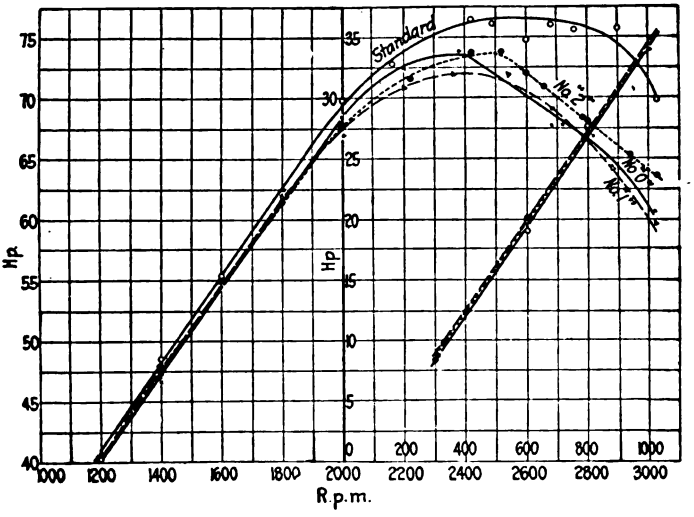
Valve-Timing

The valve-timing of an engine has, of course, considerable effect on the power, not only at low but also at high speeds. We ran some power curves on the Cadillac 1916 eight-cylinder engine at that time, all of these tests being run with the same engine, and the superposed curves are reproduced. The following timing is that given in the chart.

	Inlet opens	Inlet closes	Exhaust opens	Exhaust closes
Standard timing	3° 49′(A)	47° 29′(A)	46° 56′(B)	3° 7′(A)
No. 0 timing	1° 52′(A)	31° 22′(A)	47° 52′(B)	1° 49′(A)
No. 1 timing	2° .. (B)	32° 19′(A)	47° .. (B)	1° 10′(A)
No. 2 timing	1° 22′(A)	33° 7′(A)	43° 30′(B)	2° .. (A)

Inspection of these superposed power curves will show a slight gain up to 1000 r.p.m. in favor of the last three valve-timings, but after that point there is a slow and steady loss up to 2400 r.p.m., where there is a sudden break in the curves, while the curve run with the stand-

Digitized by Google



EFFECT OF CHANGES IN VALVE-TIMING UPON THE POWER DEVELOPED BY AN EIGHT-CYLINDER PASSENGER CAR ENGINE

ard timing shows practically no loss of power up to about 2800 r.p.m.

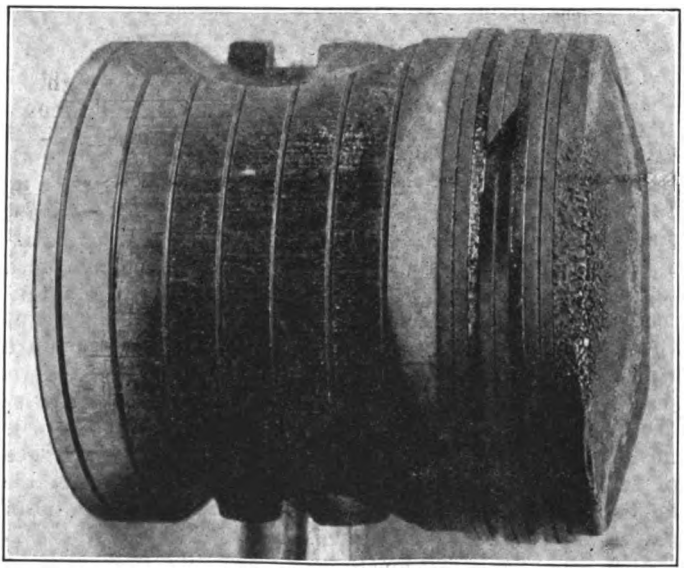
PISTONS

I have already laid considerable stress on the weight of the valve mechanism, and, of course, it is well known that the pistons should be as light as possible. I have tried various designs of piston, including aluminum, steel and cast iron of different shapes, and, so far as the touring car engine is concerned, I have not found either the aluminum or steel pistons to be satisfactory. In the first place, it is necessary to give both aluminum and steel pistons very large clearance to insure quiet running and satisfactory performance of the engine. Where aircraft engines or engines which are continually running at high speeds are concerned, it is possible that the aluminum pistons are entirely satisfactory, so far as clearances are concerned, but there is no doubt in my mind that owing to the intense changes of temperature in any engine the aluminum pistons are apt to be eaten away in very little time. An aluminum piston after a 50-hr. test on a Liberty Twelve engine is shown. This is considerably corroded and is merely an example of the effect of continuously changing temperature or quality of mixture on an aluminum alloy. The

Digitized by Google

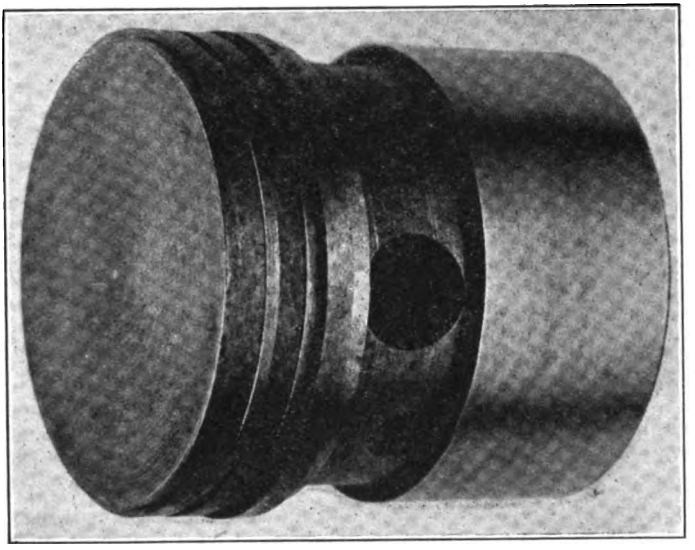
lightest form of cast-iron piston that I have been able to develop to date is also shown, the weight being 15 oz. and the diameter 3⅛ in. The surface above the wrist-pin and below the bottom groove was insufficient and the piston wore rapidly at that point.

Before leaving the interesting subject of pistons, let me mention that in multiple-cylinder high-speed engines with relatively small bores and large superficial area of combustion chamber walls, it is highy important to prevent the water, which is ever present during combustion, and the gasoline, when an enriching carbureter device is used for starting in cold weather, from getting past the pistons into the crankcase, thereby causing stoppage of lubrication by the water becoming frozen, or corrosion of parts, such as ball bearings and distributor breaker-points, where these latter essentials are included in the design of the engine, crankpin journals and mainshaft bearings. This menace cannot be too seriously considered and the only remedies lie in the accuracy of piston and cylinder fits and proper piston lubrication, both of which go hand in hand with cast-iron pistons in cast-iron cylinders. The table of piston clearances given on page



A Liberty-Twelve Aluminum Alloy Piston Showing the Corrosion Resulting from the Continuous Changing of Temperature and Quality of the Air-Fuel Mixture

Digitized by Google



A Cast-Iron Piston Weighing 15 Oz. Which Wore Rapidly above the Wrist-Pin and Below the Bottom Groove Due to Insufficient Metal

175 will be of interest as bearing upon the above points.

Valve Material

The material used in valves is very important indeed. In England, about 1913, when working with engines turning up as high as 3800 r.p.m., I used materials having the following analyses according to the speed at which the engine was to run:

Speed, r.p.m.	3,800 Per cent	3,000 Per cent
Carbon	0.400	0.320
Silicon	0.140	0.100
Sulphur	0.030	0.030
Phosphorus	0.035	0.037
Manganese	0.650	.....
Nickel	5.000	3.000

While both analyses were satisfactory, we always had more or less trouble with warping and consequent compression leakage, etc. The analysis of the valves used in the Cadillac eight-cylinder should be of interest, as we

Digitized by Google

have practically no trouble so far as our valves are concerned. The accompanying analyses are used:

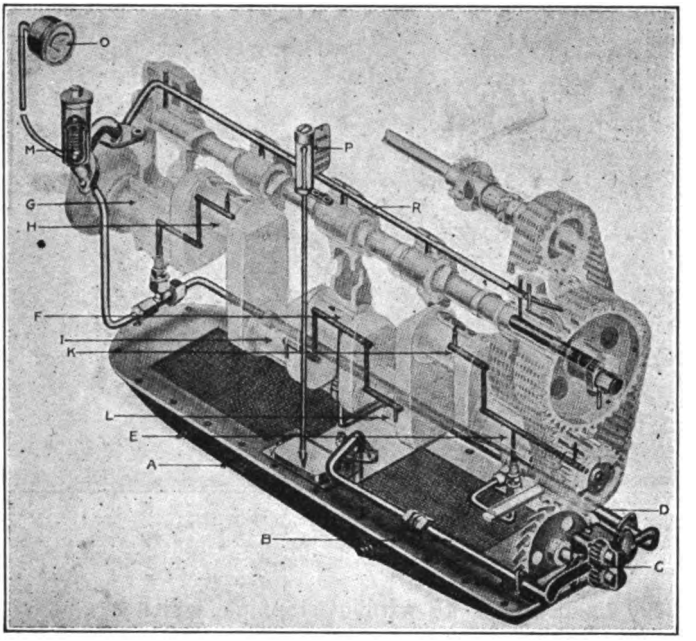
	Intake Valve Per cent	Exhaust Valve Per cent
Carbon	0.690	0.560
Manganese	0.320	0.350
Sulphur	0.012	0.016
Chromium	1.080	3.060
Tungsten	2.150	13.840
Vanadium	0.080	.....
Silicon	0.150	0.170
Nickel	0.150	0.120

Necessity for Forced Lubrication

High speeds or continued speeds under high power cannot be maintained satisfactorily without the use of forced lubrication. We had one example before us not very long ago in connection with the Liberty engine, where an attempt had been made to feed the connecting-rod crank-pin end bearings by oil thrown from the main bearings. This proved entirely unsatisfactory after tests carried out by H. M. Crane of the Wright-Martin Aircraft Corporation, John Wilkinson of the H. H. Franklin Mfg. Co. and myself, and was abandoned by agreement with the Government engineers in favor of forced feed. It is very necessary that a large volume of oil should be pumped under pressure, not merely a small one, and there should always be reservoirs with separate leads to the bearings.

The lubrication of Cadillac eight-cylinder engines is by oil under pressure. A supply of oil is carried in the oil-pan *A* and is drawn through the pipe *B* by the pump *C* and forced through the supply pipe *D* to the main bearings *E*, *F* and *G*. The connecting-rod bearings *H*, *I*, *K* and *L*, on the crankshaft, are lubricated by oil from the main bearings forced through holes drilled in the crankshaft. The pressure of the oil is regulated by an overflow valve or pressure regulator *M*, containing a valve under spring tension. When the pressure for which the valve is set is reached, it is forced open and the oil overflows past the valve. A small hole drilled in the regulator housing allows oil to by-pass the valve when it is seated. Oil flowing through the by-pass and forced past the valve is carried to the camshaft bearings and power pressure pump, in the gasoline system, through the pipe *R* above and parallel to the camshaft. The forward end

Digitized by Google

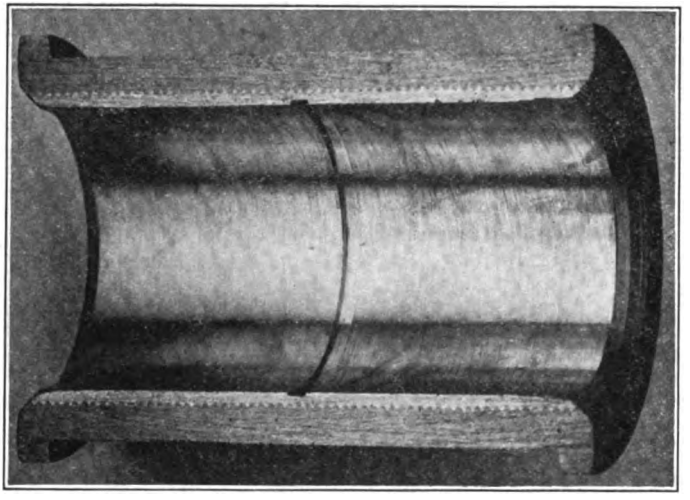


FORCED LUBRICATION SYSTEM USED ON A HIGH-SPEED EIGHT-CYLINDER PASSENGER-CAR ENGINE

of this pipe is fitted with two nozzles from which oil flows into the camshaft sprockets and to the chains through holes drilled in the camshaft sprockets. The cylinders are lubricated by oil thrown from the lower ends of the connecting-rods. There is one gage *O* located on the instrument-board and one indicator *P* in the lubricating system, attached to the upper cover of the crankcase near the carbureter, which shows the level of the oil in the oil-pan *A*.

One advantage of forced lubrication is the decrease in frictional losses. Tests made with varying oil pressures proved that the engine was quieter at the higher pressure; and the frictional horsepower was, with high oil pressure, only 60 per cent of that without pressure, and 72 per cent with medium pressure. We have carried out some very extensive tests on the Cadillac eight-cylinder engine at high speeds and have been able to maintain power for periods extending over 400 hr. at 4000 r.p.m. without adjusting the bearings at all. In addition to this we have been able to maintain maximum power at

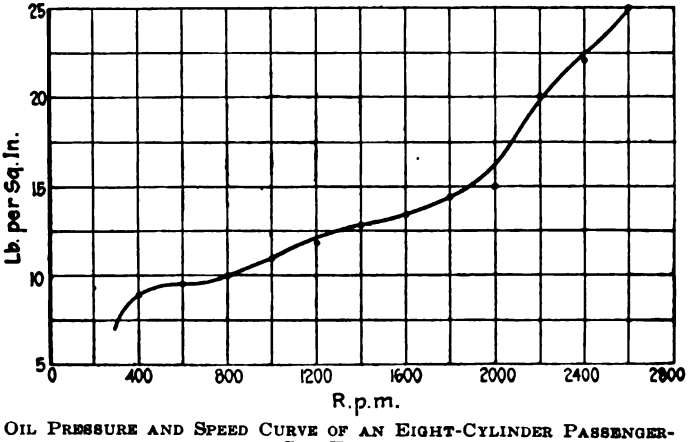
Digitized by Google



A CIRCULAR GROOVE IN THE CENTER OF THE BEARING ACTS AS A RESERVOIR FOR THE OIL AND SERVES TO DISTRIBUTE IT AROUND THE ENTIRE CIRCUMFERENCE

3000 r.p.m. for 12 hr. without stopping, which I consider to be a triumph for forced lubrication.

Some years ago I carried out tests of cast-iron and aluminum 3¼-in. pistons having different clearances, with and without extra oil supply. Table 1 shows the results obtained.



OIL PRESSURE AND SPEED CURVE OF AN EIGHT-CYLINDER PASSENGER-CAR ENGINE

Digitized by Google

INFLUENCE OF AMOUNT OF LUBRICATION ON BRAKE HORSEPOWER DEVELOPED BY ENGINES

Speed, r.p.m.,	300	600	800	1,000	1,200	1,400	1,600	1,800	2,000	2,200	2,400	2,500
Cast-Iron Pistons without Extra Oil Supply												
Clearance, in.												
0.002	3.4	9.3	12.2	15.5	18.7	20.7	22.4	23.2	23.2	19.4	18.0	17.4
0.004	3.7	8.8	12.8	15.9	18.9	21.6	22.8	23.4	22.6	23.4	21.3	20.9
0.006	4.4	9.5	13.1	16.5	19.4	22.2	23.2	24.0	24.0	24.0	20.2	20.9
0.008	4.2	9.7	13.2	16.5	19.1	22.2	24.8	25.1	23.9	22.4	20.6	19.5
Aluminum Pistons without Extra Oil Supply												
0.013	4.05	9.2	12.0	15.2	18.2	21.0	21.0	22.0	20.0	17.5	15.6	15.2
0.016	3.60	8.5	12.1	15.1	18.7	20.7	22.7	25.3	25.2	24.5	21.4	21.0
Cast-Iron Pistons with Extra Oil Supply												
0.002	4.4	9.9	13.1	17.2	20.4	22.0	23.9	25.2	25.4	24.4	21.0	20.6
0.004	4.3	9.5	13.8	17.7	21.0	24.0	25.4	25.6	27.0	25.6	26.4	25.0
0.006	4.8	10.3	14.2	17.6	21.2	24.2	25.8	27.2	28.0	27.0	27.0	24.6
0.008	4.7	10.3	14.5	17.7	21.0	24.0	25.9	26.9	27.9	27.2	27.0	24.6
Aluminum Pistons with Extra Oil Supply												
0.013	4.7	10.3	14.0	17.5	21.0	24.0	25.6	26.3	26.6	27.2	26.6	25.4
0.016	4.7	10.3	13.3	16.8	20.2	23.6	25.8	27.2	27.3	27.8	26.6	24.6

Digitized by Google

Oil grooves in bearings should be conspicuous by their absence, so far as the ordinary kind of groove is concerned. The only type of groove which I would favor is a circular one around the center of the bearing, which is actually a reservoir and tends to keep the oil completely around the circumference of the bearing so that it can reach every part. A photograph of a bearing with the groove described is reproduced.

I consider that it is important that the oil pressure should be low when the engine is throttled and increase with the speed. I have found this to be very satisfactory and it is incorporated in the Cadillac eight-cylinder engine. A self-explanatory curve, plotted between oil pressure and revolutions per minute, is reproduced.

Ignition

The most important factor in high-speed ignition is the time necessary to energize the induction coil. To compensate for this, it is necessary to increase the flow of current or lower the resistance in the primary circuit. In doing this there is excessive sparking at low speed, which oxidizes the contacts and increases the resistance, making it necessary to clean contacts at very short intervals varying from 1000 to 6000 miles. The duration of contact is very short due to the enormous number of sparks per second, and the oxidization mentioned makes one set of contacts unsatisfactory when compared with the life of a well designed multi-cylinder high-speed engine.

In view of this my company started, about the beginning of 1915, a continuous endurance run on three engines to see which part would wear out first. This run was planned to have a duration of 300 continuous hr., and we found that it was absolutely impossible to run more than 13 hr. at 2000 r.p.m. with the ordinary single-arm breaker used on the first type of eight-cylinder Cadillac engine. To overcome this serious objection, we built a distributor having two sets of contacts in parallel. Both closed and opened the primary circuit simultaneously, and, as each set carried half the current, the arcing at the contacts was reduced to a minimum. Due to the tremendous inertia at high speeds, the contacts when closing are inclined to chatter, thus causing the condenser to have a tendency to discharge and in turn producing arcing. This trouble is reduced to a minimum with two sets in parallel, as they do not chatter in syn-

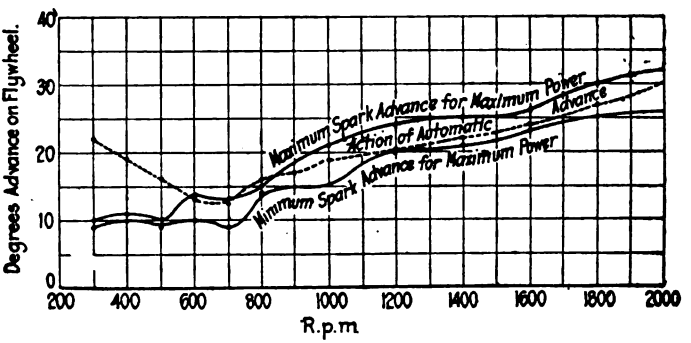
Digitized by Google

chronism, and the adjustment is not delicate. In initial adjustment one set opens late and all arcing takes place on this, causing it to waste away until it is in step with the other that opens first, so that they are synchronized automatically. This arrangement makes it possible to operate an engine at a higher speed than any other at present developed, because it increases the time to build up the induction coil by decreasing the resistance.

After this test we were able to increase the speed of our engine up to 4000 r.p.m., which means 266 sparks per sec., and after the installation of the two contacts in parallel, we were able to run a 400-hr. test without any ignition trouble, outside of occasional change of spark-plugs.

Two sets of contacts arranged to fire alternately have been used, but this makes it necessary to re-time or adjust contacts frequently, as half of the cylinders might be late in firing, which would cause a heated engine, and the other half of the cylinders might fire early, causing premature ignition or spark knocking. It would be impracticable to enlarge the contact area, because of the inertia at high speeds, as even the lightest contact arrangement is too heavy for high-speed work. If there is any eccentricity of cams and looseness of bearings with one set of contacts, these errors are very noticeable in the firing balance of the engine, but with the two sets of contacts 180 deg. apart the ignition is perfectly synchronized, a fact which is very noticeable indeed in the firing balance of the Cadillac eight-cylinder engine on block test.

I believe that the ignition as applied to the eight-cyl-



CURVE OF DEGREES OF SPARK ADVANCE ON THE FLYWHEEL AND THE SPEED OF AN EIGHT-CYLINDER PASSENGER-CAR ENGINE

Digitized by Google

inder Cadillac engine has been brought to a higher state of perfection than any other ignition.

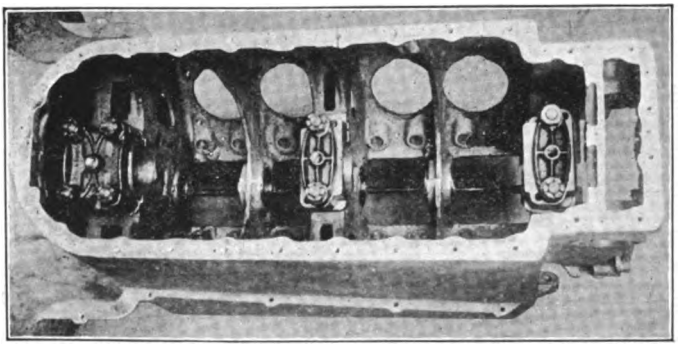
Some self-explanatory curves, giving degrees of spark advance on the flywheel relative to the number of revolutions per minute, are shown.

One can appreciate how great a factor is the inertia of the contacts, when it is stated that when running an eight-cylinder engine at 3000 r.p.m. the time between contacts is 0.0050 sec.; at 3550 r.p.m., 0.0042 sec., and at 3850 r.p.m., 0.0039 sec. With this in mind it can readily be understood that very little variation can be allowed, so that we prescribe an error of only 1 deg. between the cylinders on our engine at all speeds.

General Construction

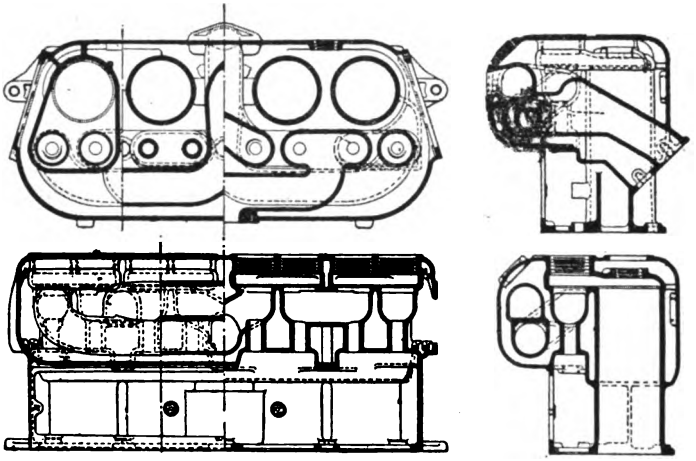
It is highly important that when engines are turning fast the maximum stiffness should be obtained in cylinders, connecting-rods and crankshafts. Above all, the crankcase should be extremely stiff and rigid to prevent weaving, bearings going out of line, etc., and thus causing vibration and other evils. In the Cadillac crankcase the method of employing reinforcing webs to give maximum rigidity is employed.

Carburetion is a difficult subject, because the quality of gasoline is rapidly becoming worse day by day. As the public becomes more critical of the performance of an automobile, the difficulties presented to the engineer become more acute. Undoubtedly, more heat must be applied to the manifolds to get proper and satisfactory carburetion, assuming, of course, that distribution is correct. We keep our manifold temperature around 170 deg.



An Example of the Use of Reinforcing Ribs to Stiffen the Crankcase

Digitized by Google



DETAILS OF A CYLINDER BLOCK IN WHICH THE EXHAUST MANIFOLD IS CAST INTEGRALLY WITH IT AND IS ENTIRELY SURROUNDED BY WATER EXCEPT ON THE TOP WHICH IS NEXT TO INTAKE MANIFOLD

fahr. by means of thermostatic control. The thermostats are located in the water-pumps, causing valves to close or open, as the case may be, and thus prevent circulation of water through the radiator when the temperature is too low. This has been very satisfactory, but with poor grades of gasoline a higher manifold temperature must be maintained. Much has been said about exhaust-heated manifolds, but these require extensive study, because too much heat is as bad as too little, and it is possible to lose much power at the higher engine speeds unless great care is taken.

An interesting development is the design for a cylinder having the exhaust cast integrally with the cylinder block and completely surrounded by water except in the wall next to the intake manifold, which is located above the exhaust manifold. The idea is that as the gases whirl the heavier molecules are thrown against the intake manifold walls, and, falling to the bottom wall, are immediately volatilized by the heat from the exhaust, the remainder of the gases being at normal water-jacket temperature. I designed this engine in 1915, and it was extremely successful, although never put into production on account of the necessary increased radiator capacity. This design, it will be seen, incorporated the "hot spot" manifold.

Various other devices are in use, such as combined in-

Digitized by Google

take and exhaust manifolds, but many of these are, in my opinion, merely makeshifts to overcome bad distribution, which, unfortunately, is so prevalent in many of our engines today.

The shuttered radiator also is a satisfactory layout, but requires considerable development owing to the danger of the shutters freezing, wind pressure causing them to remain either entirely open or closed, rattles, etc.

In the Cadillac four-cylinder 1914-type engine an electric heating element was used in the carbureter. This consisted of nichrome ribbon between mica sheets, attached to the upper surface of the diaphragm or plate that supports the venturi tube. The gasoline which condensed in the intake pipe and mixing-chamber dropped down on this diaphragm and was vaporized by the heater. In operation, current was put through the heater for a short time before starting, so that this diaphragm and the metal of the venturi tube were heated and any fuel on the diaphragm was vaporized.

Weight of Engines

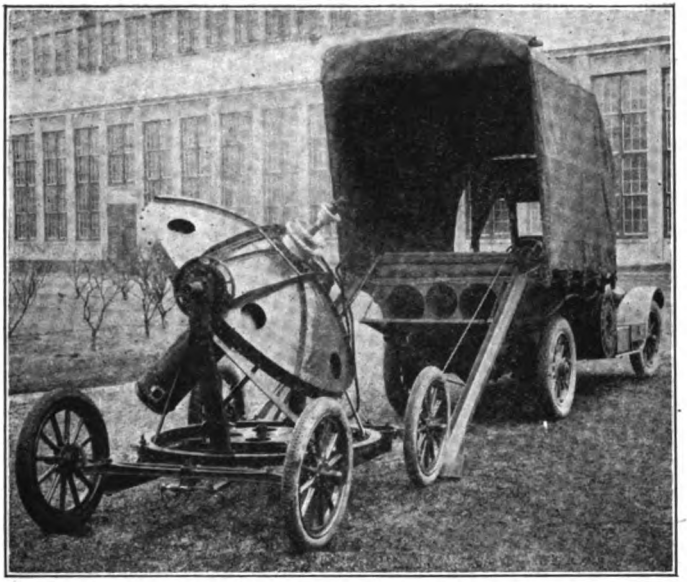
Since the advent of aircraft engines much has been learned regarding weight reduction. I am doubtful if many of the materials used in aircraft engines will ever be used in automobiles for commercial production, but we have an aluminum engine before us and there does not seem to be much doubt that in time we shall see many of these on the road and that possibly automobile engines will come down to around 4 or 5 lb. per hp. We used to dream of 7 and 8 lb. with all accessories, and I have great hope of seeing a good development in this line.

In 1909 I designed a high-speed four-cylinder engine weighing without the flywheel 5¼ lb. per b.hp. The 2½-liter Crossley engine weighed 4¾ lb., neglecting the flywheel, while the 3-liter Vauxhall in similar condition weighed 7¼ lb. per b.hp. and the Prince Henry Vauxhall, 5 lb. The Cadillac eight-cylinder engine, complete with the generator and without any flywheel, weighs 8 lb. per b.hp.

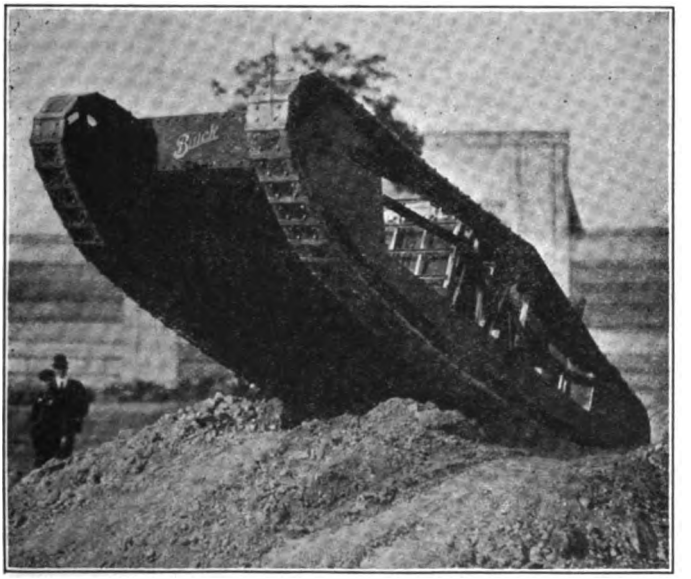
Use of High-Speed Engines

During the war the high-speed Cadillac eight-cylinder engine has been used extensively, and I have collected a few photographs illustrating the uses to which a high-speed engine has been put. One of these is a searchlight outfit developed by the General Electric Co.

Digitized by Google



An 11,000-Lb. Searchlight Outfit Having the Generator Mounted on the Chassis with the Searchlight on a Trailer That Is Carried on the Chassis when Not in Use



A British Tank Equipped with a Six-Cylinder Engine Undergoing a Test

Digitized by Google

through its engineer, Henry S. Baldwin, working in conjunction with my company. A generator having sufficient capacity to operate a 60-in. searchlight for war purposes was mounted on the chassis. We believe that this is the largest lamp that has been produced, and the car has been thoroughly tested both in this country and for about 6 weeks in France prior to the signing of the armistice. We have records which show that it has never failed to meet any demands made upon it regarding power and structural features, and all things considered it is probably one of the most unique and successful devices yet manufactured. It weighed about 11,000 lb. less than the outfit previously used for the same purpose, and the vehicle had a speed of 45 to 50 as against a former speed of 15 to 20 miles per hr. When the searchlight outfit is not in use, the trailer carrying it is pulled on top of the truck chassis.

Another example of the use of high-speed engines is in connection with tractors. The 2½-ton artillery tractor, into which was fitted the Cadillac eight-cylinder engine, was capable of traveling at a maximum speed of 21 miles per hr. This corresponds to an engine speed of 3500 r.p.m. The normal speed of the tractor is about 12 miles per hr., the engine speed on high gear then being 2000 r.p.m. The other gears at these revolutions gave speeds as follows: First speed, 3.86; second speed, 7 miles per hr. The gear ratios are as follows, the total reductions being between the engine and the track drive sprockets:

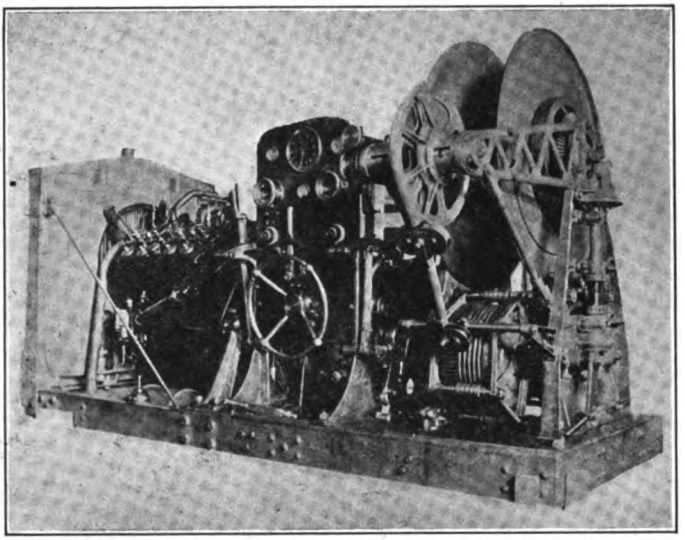
Direct or high speed—13.01 to 1
Intermediate or second speed—22.25 to 1
Low or first speed—40.50 to 1
Reverse speed—48.65 to 1

A tractor fitted with a Cadillac engine for the British Government is another application. Its space for carrying loads was forward of the radiator, instead of the load being pulled, as in the case of the 2½-ton Army tractor. The application of a Buick six-cylinder engine to the same chassis under test is illustrated.

The installation of a high-speed eight-cylinder Cadillac engine used by the British Government in conjunction with a balloon winch, particulars in connection with which can be seen from the photograph, is another use.

A photograph of a truck chassis fitted with a Cadillac

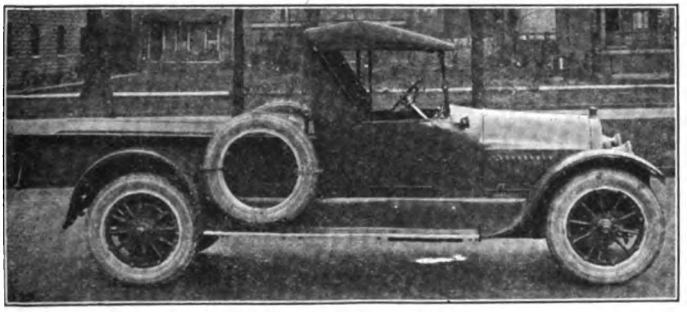
Digitized by Google



AN APPLICATION OF A HIGH-SPEED EIGHT-CYLINDER ENGINE TO A WINCH FOR A CAPTIVE BALLOON

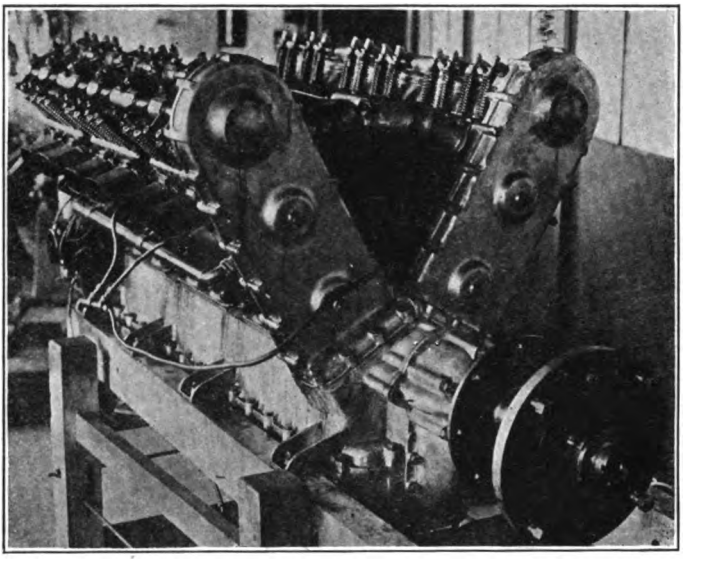
engine, which carried a load of 2160 lb., besides the driver and passenger, from Detroit to Washington, is shown. The fuel consumption averaged 10.96 miles per gal. at high speed.

A high-speed aircraft engine which I designed in 1915 is illustrated. This engine had twelve cylinders, 4 3/16-in. bore by 6-in. stroke, two exhaust and two intake valves per cylinder and three carbureters mounted in the



A TRUCK CHASSIS EQUIPPED WITH AN EIGHT-CYLINDER ENGINE WHICH CARRIED A 2160-LB. LOAD FROM DETROIT TO WASHINGTON AT HIGH SPEED WITH A FUEL CONSUMPTION OF 0.0912 GAL. PER MILE

Digitized by Google



A TWELVE-CYLINDER AIRCRAFT ENGINE HAVING TWO INTAKE AND TWO EXHAUST VALVES FOR EACH CYLINDER

center. Owing to inability to obtain battery ignition, the engine was tested with two twelve-cylinder magnetos. The engine had a dry crankcase, two oil-pumps with a cooling system and a geared-down propeller, as the engine was designed to pull 350 hp. at 2400 r.p.m. It weighed with cast-iron cylinders 1000 lb., which, of course, amounts to 3½ lb. per hp. This weight could have been very considerably reduced with steel cylinders.

THE DISCUSSION

R. K. JACK: I would like to have Mr. White's opinion as to the suitability of using the slipper-type piston on an airplane engine of large bore, say about 145 mm. We ran a test of over 50 hr., using aluminum pistons of this type, on a 500-hp. engine a few months ago, and at the end of this run the pistons were in splendid condition. The conventional type did not show up so well.

MR. WHITE: It may be that this slipper type of piston to which Mr. Jack refers is one where the surface on the sides is materially reduced, like the old steam engine slipper guide. While this piston might be lighter, I think it would be difficult to keep it round, especially for touring car work.

Digitized by Google

THE STORY OF THE UNITED STATES STANDARD TRUCK

By J G Utz[1]

THE United States was practically unprepared in the field of military motor-transport at the beginning of the war. Due largely to the cooperation of the Society of Automotive Engineers and its members individually, this handicap was overcome and a position stronger in this respect than that of any of the other belligerents was attained. The early efforts and the cooperation between the Society and the various Government departments are described, especially with reference to the Quartermaster Corps which at that time had charge of all motor transportation.

Regarding the Class B truck, it is shown that the Society acted as a point of contact between the various members of the industry and the War Department and, although not fostering any program or plan of its own, it was largely responsible for the success of the standardization program conceived and carried out by the Army. This standardization program has been amply justified by the history of the production of this truck, as well as by the record it made in this country and overseas. The advantages and the absolute necessity for standardization are emphasized by the fact that 214 types of vehicle were used by the American troops in France. The absurdity of maintaining and operating such a heterogeneous collection of vehicles is obvious, because the Army motor-transport could have been handled by a total of fourteen types.

The value of cooperation between the Society and Army has thus been amply demonstrated. This, in itself, emphasizes the necessity for even greater cooperation in the future.

It is interesting to note the historical fact that the British Army first used motor trucks in 1903, thus giving them eleven years' experience to guide them when they entered the war in 1914.

The first use of motor trucks by the United States Army was in January, 1912, when two 1½-ton trucks were purchased by the office of the Quartermaster General for the purpose of testing them out and determining their fitness for military use. From results obtained in these tests, later in this year Lieut.-Col. C. B. Baker began to

[1]Director of engineering, Standard Parts Co., Cleveland, Ohio.

Digitized by Google

prepare specifications for the purchase of motor trucks for the Army after having first communicated with several manufacturers and secured their suggestions and recommendations.

On May 7, 1913, the first specifications for 1½-ton trucks for U. S. Army use were issued, and from these a very few trucks were purchased. These specifications were revised and reissued on March 31, 1915. About this time the Society of Automobile Engineers, inspired by the use made of motor vehicles by the combatants in the great world war, began to take active interest in the use of motor transport for military purposes, and some correspondence passed between Past-presidents Dunham and Coffin in regard to the Society offering the Government its cooperation, not only in the preparation of specifications, but in the survey of the industry and automotive equipment already in use, with a view to the organization of such for military use should emergency arise.

On April 28, 1916, Colonel Baker, then chief of transportation in the office of the Quartermaster General, wrote the Society announcing the intention to issue revised specifications which would include both 1½ and 3-ton trucks, and requested the Society to cooperate in the preparation of these specifications. Colonel Baker was no doubt inspired by his memories of '98, when the Spanish War broke out, and the Transportation Division of the Quartermaster Corps, had to rush into the open market and purchase a heterogeneous lot of wagons, with all the attendant difficulties of keeping them in repair. Incidentally, Colonel Baker was instrumental in standardizing the mule-power Army escort wagon, which today has simplified the interchangeability of wheels and other parts. It was not until about 1906 that all the non-standardized wagons purchased in 1898 were worn out, the U. S. A. escort wagon remaining the standard.

The First Conference

On May 8, 1916, the Society, in cooperation with the National Automobile Chamber of Commerce, invited about fifty truck manufacturers to send their engineers to the offices of the Society for the purpose of complying with Colonel Baker's request. This meeting was presided over by the late Henry Souther, then consulting engineer for the Signal Corps, who acted for President Huff of the Society. After a broad discussion by the entire body, a representative committee of truck engineers was formed

Digitized by Google

for further cooperation with Colonel Baker. This committee consisted of the engineers of five companies manufacturing trucks, five companies assembling trucks, and an engineer of a truck factory not making the type of truck being deliberated upon. The members of this committee were as follows:

A. L. Riker.....Locomobile Co. of America
H. D. Church.....Packard Motor Car Co.
W. R. Strickland.....Peerless Motor Car Co.
John Younger.....Pierce-Arrow Motor Car Co.
L. P. Kalb.....Kelly Motor Truck Co.
B. B. Bachman.....Autocar Co.
G. W. Smith.....Nash Motors Co.
W. T. Norton.....Selden Motor Vehicle Co.
E. R. Whitney.....Commercial Truck Co. of America
A. J. Scaife.....White Co.
F. A. Whitten.....General Motors Truck Co.

The committee went into session on the same day with Colonel Baker and W. M. Britton, engineer for Colonel Baker's office, taking up various points in the specifications which Colonel Baker submitted. On account of the limited time, very few changes were made in the specifications as presented, and they were issued in June, 1916.

About this time the Government placed rush orders for the first large quantities of trucks that it had used. These were for use on the Mexican border, and the bulk of the orders were given to about four companies, they being chosen, evidently, according to their ability to make rapid deliveries. This fact is peculiarly interesting, as it was with these trucks that the officers of the Army obtained their first large-scale experience with motor transportation. These trucks operated under most severe conditions, due to lack of roads, lack of organization, and unfamiliarity of officers, drivers, etc., with motor problems. This service constituted the most severe test to which trucks could be put on so large a scale.

Thus we should thank Francisco Villa for the beginning of the Motor Transport Corps of the U. S. Army. Fairly complete data were collected of the performance of these trucks, giving an interesting record of the shortcomings of commercial vehicles in army service.

On July 31, 1916, there was a meeting of the General Staff Committee on Motor Transportation with representatives of the automotive industry. Several of them were prominent members of this Society. At this meeting

Digitized by Google

the subject of motor transportation was discussed in a very broad way; the matter of types of vehicles, the sources of supply, specifications, organization of truck companies, training of drivers, mechanics, etc., being gone into. It is not known just what resulted from this meeting, but it is considered one of the important steps in the cooperation between the Army and the members of the automotive industry.

The Military Truck Committee of the Society, which had been appointed on May 8 to cooperate with Colonel Baker in the preparation of military truck specifications, was later formed into the Truck Standards Division of the Standards Committee, its principal function being continued cooperation with the Government in this work. This committee continued to hold meetings from time to time, preparing an ideal military truck specification which they intended to submit to Army authorities. On Oct. 13, 1916, tentative specifications were submitted to the Standards Committee for criticism, and these were discussed and revamped at several meetings following this. On Jan. 5, 1917, a conference was held between the Motor Transport Committee of the War Department and two chosen representatives of the Truck Standards Division. At this meeting there were discussed certain fundamental matters of the specifications under consideration, based on Mexican border experiences.

Preparation of New Specifications

A little later, Colonel Baker informed the Society that a new set of specifications was being prepared by his office, taking into consideration recommendations of the Truck Standards Committee, as expressed in the tentative specifications submitted by that body. He asked that the members of the committee meet him in Washington on March 19 and 20, for the purpose of discussing and criticising these specifications before they were issued. This meeting was held at the time mentioned, at which were present not only the members of the Truck Standards Division, but also General Manager Clarkson and the chairman of the Standards Committee. The specifications were discussed at as great length as time would permit. Members of the Truck Standards Committee made some strong exceptions to certain points, Colonel Baker overruling some of the exceptions and concurring in others. Following this conference there were published in May, 1917, Standard Specifications for Class A and

Digitized by Google

Class B gasoline motor trucks. These specifications, while going into great detail, call special attention to the following fundamental items which were considered of vital importance for military trucks.

(1) Low gear reduction
(2) Large size engine
(3) Four-speed transmission with very low first speed
(4) Maximum ground clearance
(5) Demountable tires of specified size and composition
(6) Large gasoline tank
(7) Electric lighting system
(8) Three-point engine suspension
(9) Locking differential
(10) Best quality alloy steel springs
(11) Gage of wheels
(12) Large radiator

These specifications called for some radical features of design which could not be made in existing models of trucks. However, it had been stated a number of times by Colonel Baker and other representatives of the War Department that it was not the intention to work a hardship on the motor truck industry, but that the specifications would be considered an ideal which would be worked toward when time should permit. At a meeting on April 6, at which were present Secretary of War Baker, Col. C. B. Baker, representing the office of the Quartermaster General, and officials of the National Automobile Chamber of Commerce, this principle was restated, and it was announced by Colonel Baker that he was anxious to arrange for motor vehicles in such a way that it would disturb as little as possible the general routine work of the automobile factories. It was also stated that early requirements would be cared for with present types of trucks, preference being given to those most nearly conforming to the printed specifications.

In the light of the past eighteen months' experience, some of the features of these specifications may seem somewhat ill advised, but it must be remembered that at that time our sum of knowledge in regard to military motor transportation was very much smaller than it is now, and the experience then in the possession of our Army had all been gained on the Mexican border, which, we know now, furnished quite different conditions from those that obtained on the western front, until the last few weeks of the war furnished some bad road conditions. Although there were a number of engineers who disagreed with the specifications, their arguments were

Digitized by Google

offset by the fact that no one knew on just what front the United States would be forced to fight, and it was considered advisable to issue specifications calling for a truck able to meet the most severe conditions, whether in Russia, Macedonia, Italy or France.

It has since been found that some of the fundamental principles of these specifications were based on incorrect premises. Nevertheless, it can be stated without fear of contradiction, that the May, 1917, specifications were the best of any yet produced, and marked a very great step in the way of cooperation between the Army and the automotive industry.

About this time we declared war on Germany, and an inventory found our Army possessed of about 2400 trucks. The Army was confronted with the need of adequate motor transport and its twin problem of immediate procurement.

Production Difficulties

Immediately after the issuing of the specifications a number of truck manufacturers took steps to produce trucks which would meet the most important if not all the detailed requirements called for therein. Those companies producing all of the component parts of their own vehicles found this no insurmountable task, but those organizations buying all or part of their major units were met by the fact that none of the parts companies had produced or were contemplating the production of parts to meet the specifications. Since the contemplated requirements of the Army were going to be so great that a large number of different makes of trucks, with the attendant repair difficulties, would have to be purchased, it was evident that some degree of standardization had to be effected or the repair parts depots in France would be swamped. Since the Society has always been the exponent of standardization and presented the only clearing house for automotive engineers, it necessarily followed that it should be called upon by different members for assistance. After a number of inquiries had been received by the various engine, axle and transmission makers, they, of course, became very much interested in this proposition, and a large number of requests for information as to how best to meet the specifications were received by the Society.

On May 3, at the Quarterly Meeting in Cleveland, the Standards Committee ratified the Quartermaster Corps

Digitized by Google

specifications, and so advised Colonel Baker in a letter prepared on that date and signed by the Chairman of the Standards Committee and General Manager Clarkson. At that time a meeting of the newly formed Transmission Division was held, at which the principal topic of discussion was proper means and steps necessary to be taken in order to meet the Government specifications. On May 14, 1917, a meeting of the Truck Standards Committee was held in Washington to discuss special features called for in the specifications, such as bumpers, towing hooks, air cleaners, magneto brackets, etc., which, it was felt, should be standardized and made interchangeable between the various trucks then being developed to meet the specifications.

On June 2, 1917, a meeting of transmission makers and engine makers, as well as of the engineers of a few truck factories, was held in the Society rooms at Washington for further discussion of means for meeting the specifications. These discussions at once disclosed the effect that the work of these two groups would have on all of the other parts of the trucks, and on June 14, 15 and 16 further meetings were held at the Willard Hotel in Washington, at which were present representatives of the axle, universal-joint, radiator, bearing, frame and spring makers. Practically from the first of these meetings the possibility of effecting some degree of standardization or interchangeability was realized. Some of the transmission makers, especially those who had not previously produced truck transmissions, were in favor of a complete interchangeable design, while the makers of the other important units, as well as a good proportion of the transmission makers, favored only the interchangeability of entire units. In other words, the object was for each parts maker to design and produce his product in such a manner as to make it possible to replace one make with another.

This was at that time considered the logical course, as it did not affect the equipment and tools of various parts manufacturers to so great an extent as complete standardization would have done; further, it gave some of the main advantages of complete interchangeability without limiting the parts maker and depriving him of the possibility of improving his product. It can be seen that up to this time the matter of standardization had sprung up almost spontaneously as a direct result of the May specifications. It is not believed that at that time

Digitized by Google

anyone, unless it were Col. Baker, had any idea that this work would lead to the complete design and the standardization of the military truck. The part which the Society had played was merely that of an agency bringing together the various engineers, helping to coordinate their work and to assist in enlightening all of the manufacturers of trucks and parts in the best way to meet the specifications.

Society Discusses Standardization

At the summer meeting of the Society, held in Washington on June 25, 26 and 27, the motor-truck standardization proposition had assumed considerable proportions, and whereas in previous meetings all of the engineers had been divided into groups considering the various parts, with whatever truck engineers that were present acting as free lances, giving advice to all of the committees, at this meeting an organization of the truck engineers was effected. It was considered that the work of the various parts committees had proceeded far enough so that the general layouts and designs of the chassis could be made. The work up to this time was mainly on the 1½-ton size truck, but the larger size was always kept in mind and records were kept of all the progress on anything which would apply to the larger model.

At this Washington meeting there were present a number of the engineers of the so-called old-line truck builders, and some concerted opposition to the program was offered by them. At one of the meetings the spokesman for this group, John Younger, objected to what he called piecemeal standardization, and advocated the complete standardization and design of all parts of the vehicle. He offered to give the benefit of his experiences in any such effort as this. The next meeting was held in Columbus, Ohio, on July 9, 1917, at Ohio State University. The meeting had assumed much larger proportions by this time, and the chassis committee had reached such a size that it was found necessary to effect a permanent organization and arrange for meetings to be held separately from the other groups. A meeting of this committee was held July 17, 1917, in Detroit, and good progress was made in settling some of the fundamental principles of chassis design.

The work of all the committees had progressed to such an extent that it was thought that one more meeting

Digitized by Google

would be sufficient to wind up the entire matter, and that it would then be possible to put the work of all the committees down in black and white and issue a manual or specification by which all parts makers or truck assemblers would be guided. This meeting was called for July 20, 1917, at Columbus, Ohio. Not only were the members of the various committees invited to this meeting, but a special invitation was given also to at least sixty truck manufacturers to have their executives present, and a free discussion was requested. On the day previous to this meeting, the representatives of some of the old-line builders met at the Deshler Hotel in Columbus, and discussed the situation as it seemed to affect their companies. It was the consensus of opinion of all those present that it would be a dangerous experiment for the Government to proceed with the program, and George Graham of the Pierce-Arrow Motor Car Co., was chosen as spokesman to present their views to the meeting to be held on the next day.

In the meantime, the members of Col. Baker's office staff had a vision of a 100 per cent standardized truck —in other words, a complete new vehicle to be designed in the War Department and later ordered to drawings and specifications. This step was clearly out of the province of the Society, as it would immediately involve engineering, drafting and experimental expense. When Col. Baker's office was notified of this condition by officials of the Society, his office decided to assume the burden. A request was therefore directed to Secretary of War Baker for an appropriation of $175,000 to be granted to Col. Baker's office to finance the cost of engineering and construction of sample trucks for further consideration. The appropriation was promptly granted and Major (now Brigadier-General) C. B. Drake and Captain Britton were directed to travel to Columbus to notify the industry at its meeting of the new move.

At the meeting General Manager Clarkson gave a history of the work of the military truck standardization up to that time, after which Mr. Graham asked for the floor and presented the arguments and views of the various truck makers who were opposed to the standardization program. Mr. Younger also spoke in support of these remarks and several other members spoke in defense of the program. Major Drake and Captain Britton were then introduced. The former spoke somewhat briefly and expressed the appreciation of the office of Quarter-

Digitized by Google

master General for the assistance of the Society. Captain Britton announced the decision of the War Department to carry out the complete design and standardization of Class A and B War Trucks.

War Department Begins Design Work

This really ended the official connection of the S. A. E. as a society with the standardized truck. A number of the engineers who had cooperated in the work up to this date were later asked to go to Washington to assist in this design, the greater part of these engineers being called to Washington to commence work about Aug. 1. It must be remembered that all previous work had been done on such items as attaching brackets, connecting flanges, etc., the object being interchangeability of units only; although a great deal of the work already done was of value to the work which followed, there was a great deal more work to be done than had been done.

The new work in Washington was greatly handicapped at the beginning due to lack of proper quarters, drawing-boards and other facilities. The worst handicap, however, was the lack of competent direction and organization, there being no definite channels of authority or responsibility. So great was this handicap that practically the entire month of August was spent in preliminary layouts before several fundamental principles, such as type of axle, bore and stroke of engine, location of clutch and method of spring-shackle lubrication were settled. In order to correct this, a Schedule Committee, with A. W. Copland as chairman, was formed, consisting of the chairmen of the various groups. The nominal object of this committee was to set time schedules for the completion of the work and to make certain the meeting of these schedules. To accomplish their object it was necessary for this committee to assist in making some important decisions, which, as stated above, had not yet been made. From this on, the work went forward rapidly and the Schedule Committee felt able to set Sept. 10, 1917, as the date upon which the design should be completed.

The design of the various parts was practically 90 per cent complete on this date, and the chassis design was finished a few days later. By Oct. 1 all the designs, details and checking were ready. Oct. 10 was set as the date for the completion of the two sample trucks, and one was actually ready three days ahead and the other one day ahead of schedule. The total time

Digitized by Google

elapsed between the calling together of the engineers to begin work and the completion of the first sample truck was sixty-nine days, a very creditable record, and one which has never been equalled in the motor-car industry.

The two trucks were driven overland to Washington, one of them being required to cross the Allegheny Mountains in the first snowstorm of the year. They arrived in excellent condition, and the engineers and drivers who accompanied these trucks expressed great satisfaction with their performance. On Oct. 19 the trucks were presented by Col. Baker to Secretary Baker in a formal ceremony at the State, War and Navy Building, and were afterward driven to the White House, where they were examined by President Wilson.

Quantity Production Commenced

The General Staff and Secretary Baker having authorized the procurement and production of 10,000 of these Class B Trucks, under the direction of Col. Baker, it became necessary to proceed rapidly. Several prominent men from the industry were considered, and finally Quartermaster-General Sharpe, at Col. Baker's request, practically commandeered the services of Christian Girl. Mr. Girl little relished the job, fully realizing the criticism he would be subjected to by opponents of standardization, as well as hidden obstacles that would be put in his path. Up to the time his services were "drafted," he had small knowledge of what had transpired, and stood practically in the position of a factory manager who is given a set of prints and directed to "build 10,000 of these whether you like it or not." He was finally persuaded that it was his patriotic duty to acquiesce, and after three days at home to put his private and company affairs in shape, he returned to Washington on Sept. 6, 1917, and organized what was known as the Military Truck Production Section of the Transportation Division of the Quartermaster Corps. The organization which he built up around him consisted of men thoroughly familiar with the various branches of the automobile industry. He attempted to fill each position with a man especially fitted by years of training and experience. This was something theretofore unknown in the War Department, it being an old rule in the Army that an officer is supposed to be able to handle any class of work, no matter what his previous experience. Herein Col. Baker

Digitized by Google

raised himself above the traditions of his contemporaries.

The duties of the production organization were to

(1) Survey all plants of prospective producers for capacity in every respect as regards ability to produce articles of which purchase was to be made
(2) Report the names of parts makers for raw material for priority action through the Automotive Products Section of the War Industries Board
(3) See that parts were produced according to schedule
(4) See that trucks were delivered on schedule time
(5) Inspect all purchases from raw material to finished product; including also the testing of trucks

An organization to handle this work was built up in a very short time, and it can be seen that no small organization could handle such a task.

The Production Department, being composed of civilians, did not make a single purchase, merely presenting data to the Purchasing Board, which was composed as follows:

Col. C. B. Baker, chairman; Col. Charles B. Drake, Lieut.-Col. James W. Furlow, Major Edward Orton, Jr., and Capt. L. H. Coart, secretary.

The work of plant survey, securing of bids, etc., progressed at an unusual rate of speed, and early in November contracts were let, both for parts and for chassis assembly. In all cases it was attempted to have at least three purveyors for each part, while the chassis assembly was divided among seventeen truck builders, the smallest number given to any one maker being 500 and the largest 1000. In spite of unanticipated obstacles, consisting of freight congestion, lack of fuel and opposition to commissioning inspectors to comply with Army regulations, production came through in a very satisfactory manner, and five trucks, which were rushed through as a check on the tools were completed about Jan. 10, 1918.

By April, 1918, production was proceeding so satisfactorily that the General Staff authorized the purchase of an additional 8000 of these vehicles. In August, 1918, an additional 25,000 were authorized, and had the armistice not been signed these would have been well in production by this time.

There have been many criticisms since the beginning of the standardized military truck program. Before the

Digitized by Google

truck was designed and production commenced, there were many predictions of failure, it being stated that a truck brought out in so short a time would surely have some fatal errors of design which would probably greatly delay production. In view of some inherent defects which developed in a few of the stock trucks in the A. E. F., which defects did not develop in the Class B trucks, the demand that the B truck be abandoned early in its history was ill-founded. It was further stated that these trucks could not be produced in time to be of value, and that it would seriously delay the military program if the Quartermaster Corps attempted to carry out this program.

Results have shown these fears and predictions to be groundless. In fact, there has never been a time when production and delivery of Class B trucks at the ports of embarkation have not exceeded the allotted cargo space.

Production Difficulties

After trucks were in production, a number of troubles were, of course, encountered, the majority of them being manufacturing difficulties; some, however, were design faults, and at the time they were discovered, loomed up very large. However, the Engineering Department, which had by that time been built up into a permanent organization with a more complete testing and experimental department than any truck manufacturer in the country can boast of, attacked these problems with determination, and, with the efficient aid of the manufacturers involved, was able to overcome every difficulty that arose. It is unfortunate that a larger number of these trucks were not shipped to France and put into active service. It was evident that influence was exerted in the A. E. F. to prevent B trucks from being ordered overseas; just why it cannot be stated, for, if the truck were a failure, service in the A. E. F. would soon have condemned it. I found evidence in France, when I arrived at general headquarters there in May, 1918, that propaganda had been spread to the effect that the B truck was a failure, and they did not want them in France. Everyone who has had experience with the Class B trucks, either in this country or on the other side, agrees that it is the greatest thing of its kind ever produced. I have accompanied several convoys of these trucks across the Allegheny Mountains, have seen them

Digitized by Google

in operation in France, have interviewed numerous convoy officers, have letters from officers of the American Expeditionary Force in charge of these trucks, and am firmly convinced by the great bulk of this testimony that the Class B truck is an unqualified success.

The various details of construction have been described in papers read before the Society, by men who had an active part in this work, so that it is not considered necessary to give a repetition of that information in this paper. There is one feature of this design, however, which I consider worthy of mention at this time, as it is bound to have a marked effect on future commercial vehicle design, and that is the truck's unusual amount of low-gear ability. The military truck specifications laid great stress on this point and went so far as to define it by means of a so-called "tractive factor." Later experience has proved that the figure specified for high-gear ability was somewhat in excess of the proper amount for good economy, as well as satisfactory performance.

The low-gear ability specified, however, has justified itself to such an extent that there is today a decided trend among truck engineers in this direction. Four-speed transmissions, with a very low-gear ratio giving all the tractive effort that the adhesion of the tires will permit, will undoubtedly be incorporated in the design of a great majority of high-grade trucks within the coming year. This consideration, coupled with the possible advent of "locking-type" differentials, makes necessary axle drive-shafts of sufficient size to slip the wheels.

It is very unfortunate that the Class A and Class AA trucks were not put into production, since these would have given the Government a consistent line of trucks capable of taking care of practically all the needs of the Army motor transport, with all of the advantages that standardization gives.

Trucks in Service in France

Experience of the American Motor Transport in France has demonstrated beyond question the value of standardization. Due partly to lack of shipping space, causing the necessity for purchases of motor equipment in Europe, as well as to the numerous motor transport programs of the various departments of the Army, there were 214 makes of motor vehicles used by the American troops in France. You may be able to imagine the confu-

Digitized by Google

sion in the maintenance department and the number of spare parts which had to be carried in order to attempt anything like proper upkeep and operation of these vehicles. The fact is, that it was impossible to carry sufficient parts to maintain a large number of these miscellaneous types, and when a part failed, it was necessary to either junk the vehicle or rob another one already out of commission for some other cause. Here began the outstanding evil in Army motor maintenance, which remains; the need of tens of thousands of different kinds of spare parts and accessories for up-keep. The Motor Transport Corps of the A. E. F. was required to keep 57,000 non-interchangeable parts in stock, besides 13,000 kinds of bolts, nuts and screws—a total of 70,000 separate items. Our general "unpreparedness for war" may be blamed for some of the difficulty, but the lesson has been sad and expensive, and it is hoped it will not be repeated should we ever be so unfortunate as to have another war.

The absurdity of attempting to maintain and operate such a heterogeneous collection of vehicles is evident when it is remembered that the army motor transport could have been handled by a total of fourteen types. The following list needs no argument to support it:

(1) Light five-passenger car
(2) Heavy seven-passenger car
(3) ¾ to 1-ton truck
(4) 1½ to 2-ton truck
(5) 3 to 5-ton truck
(6) Cargo caterpillar or four-wheel-drive type of truck
(7) Motorcycle
(8) ¾-ton trailer, cart type
(9) 1½-ton trailer, cart type
(10) 1½-ton trailer, four-wheel type
(11) 3 to 4-ton trailer, four-wheel type
(12) 6 to 7-ton trailer, four-wheel type
(13) 10-ton trailer, four-wheel type
(14) Bicycle

Cooperation Between Society and Army

The value of the cooperation which the Society has given the Army has been proved at every step. The military truck specifications are admitted to be the best of their kind ever produced, the Class B truck is a proved success, and this in itself demonstrates how successful the whole standardization pro-

Digitized by Google

gram would have been had it been carried out. Practically all automotive engineers who have been serving the Government during the war either have or will shortly sever their connections to resume their peace-time occupations. In fact, with the present limitations on salary of Army officers and other Government employes, it would be impossible for the Motor Transport Corps to induce many engineers of standing to remain in its employ. This means that there must be even greater cooperation in the future between the Society and the Motor Transport Corps, than there has been in the past.

We have profited greatly by our experience in this line, and it can safely be predicted that the results of future cooperation will be of even greater value than those of the past. It has been demonstrated that standard trucks, like standard escort wagons, can be ordered and delivered quickly in quantities when emergency arises, and any truck builder can build the trucks, just as any wagon builder can build the wagons, when once their value and ultimate economy are appreciated.

Digitized by Google

MORE EFFICIENT UTILIZATION OF FUEL

By Charles F Kettering[1]

IN general, this article, which was presented to awaken interest and stimulate curiosity in a subject of vital importance to the automotive industry, deals with the fundamentals of combustion of various fuels in internal-combustion engines. The discussion includes broadly

(1) The importance of chemical structure in the study of fuels. Such knowledge is necessary to understand refining processes and the reactions taking place during combustion in a gas engine.

(2) Boiling points versus specific gravity of fuels. Specific gravity is a term of slight moment; it has nothing to do with what fuel really is or how it performs in service. The distillation curve is the best index of a fuel's suitability

(3) Benzol and alcohol as engine fuels. Further proof that chemical structure plays a prominent part in fuel performance

(4) The phenomenon called "engine knocking." Theory is proposed that knocking is caused largely by change of fuel structure into secondary or intermediate compounds, the so-called "detonable compounds," during combustion. This theory is based upon the fact that fuels, capable of high compression without any knocking tendency, are compounds which do not decompose at low temperatures and pressures

(5) Pressure-volume and pressure-time indicator cards and their interpretation. The cards show genuine preignition, normal combustion and fuel knocks

(6) High-compression fuels and engine performance; again showing that certain chemical structures possess high critical temperatures and pressures

(7) Some of the specific fuel problems

[1]President, Dayton Engineering Laboratories Co., Dayton, Ohio.

Digitized by Google

(8) The need of more effective co-operation. On account of the constantly decreasing quality of fuels, investigation and study of the situation become imperative

As far as the automotive engineer is concerned, there are two problems involved in the fuel situation, each of which is of great importance. These have to do with the application of fuel to an internal-combustion engine. One is getting the fuel into the engine, and the other is burning it there.

To get the fuel into the engine, innumerable devices have been constructed and given consideration, and yet I think we all recognize that the results from these have been disappointing, because they did not solve the problem that really needed solving; namely, what happens inside of the cylinder. Having recognized this condition of practically complete ignorance as regards what goes on within the cylinder of an engine during operation, we started to see what we could find out about it. Naturally it is a little difficult to sit around in a cylinder while it is in operation and tell just what happens there, so we had to devise means of staying outside and still telling what was going on inside. In doing this, we had to build some new instruments, and theorize. The result is that some things I am going to tell you may not be true, but it is not my fault if they are not.

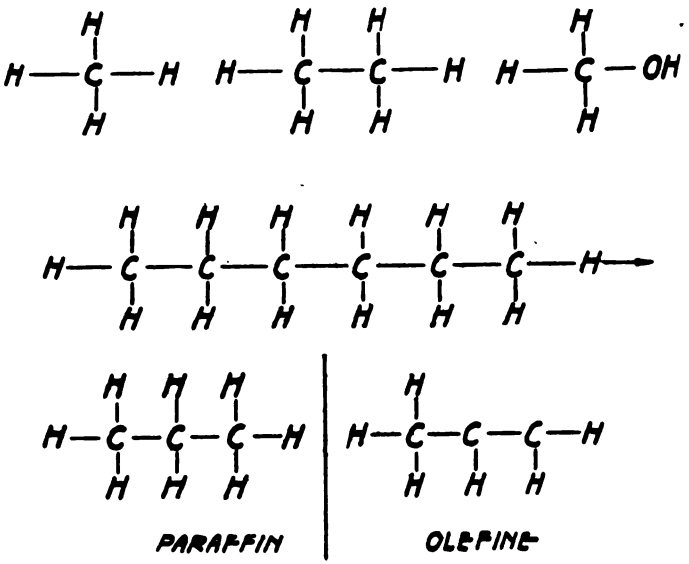
In discussing the question of fuels I think it would be well to go back a little. Our present idea of fuel is that a satisfactory fuel must have a certain gravity. I want to go into the fuel situation a little more deeply than merely determining its uses according to its gravity. It has been a general observation that as we lower the gravity of a fuel, such as the present commercial fuels on the market, even though we get the fuel properly distributed, we have to lower the compression of the engine because of the knock which results. This knock is the kerosene knock, preignition, pinging, or whatever it is called. To make my subsequent discussion somewhat more intelligible I want to first discuss briefly the construction of a fuel, its relation to gravity, etc.. and then what happens when we try to burn it.

Chemical Composition

All of our fuels are hydrocarbons. I think we have all studied the subject enough to know that a hydrocarbon is a very uncertain and miscellaneous individual,

Digitized by Google

consisting of varying combinations of carbon and hydrogen. If we start out with carbon we see that it is a four-valent element; that is, it has the ability to combine with four uni-valent atoms, such as hydrogen. The simplest hydrocarbon combination is that in which four hydrogen atoms are combined with a single carbon atom, the bonds uniting the hydrogens with the carbons being as indicated. This compound is methane, which is a large constituent of natural gas. The chemistry of the hydrocarbons would not be very difficult if it always worked out as in the case of methane; that is, if each carbon atom always united with four hydrogen atoms, or four uni-valent atoms. But the carbon also has the ability to combine with itself, that is, to satisfy certain of its chemical bonds by combining with other carbon atoms. It is quite possible to have another compound in which two carbon atoms are united, each in addition having certain hydrogen atoms united with it. The first compound referred to above is said to have the formula CH_4 and the second the formula C_2H_6; but I will show that such a formula really means nothing. If we insert another carbon atom between the other two and



SOME OF THE SIMPLER HYDROCARBON COMPOUNDS AND WHAT HAPPENS WHEN A COMPLEX ONE IS CRACKED

Digitized by Google

add the two hydrogen atoms to it, we get a third hydrocarbon, the formula for which is C_3H_8. In other words, if we take a series like this and add a carbon atom each time, with its corresponding hydrogen atoms, we get a general formula which may be expressed thus: C_nH_{2n+2} In this series the compounds become very long, and increase correspondingly in gravity. This increase in gravity gives a corresponding increase in the boiling point, and that boiling is only a simple way of measuring the weight of a molecule.

We have heard considerable talk about cracking. Now suppose we take one of these big-molecule compounds and break it in two. We will get two smaller compounds. We might have to throw away some of the carbon because if we break such a compound in two we will not have enough hydrogen for the end carbons. This does not necessarily follow, however, for it is possible to have a compound which apparently has not enough hydrogen in it. If we take one of these heavier hydrocarbons, for instance, and crack it in two we have as one compound a paraffin which is analogous to the compounds shown above, and as the remainder another compound which is obviously different from those called paraffins; such compounds being given the general name of olefins. The olefins have a general chemical formula of C_nH_{2n}. The cracking process then consists in breaking up these larger molecules into smaller ones. In breaking up hydrocarbons we put them in a big drum, hit them and hammer around and finally they get sore, as it were, and say, "What's the use? We might as well break up." That is exactly the way we get an increased volume of gasoline. There is, of course, some loss in throwing away carbon. I want you to keep this in mind, however: that, if heating under pressure and high temperature produces disintegration of these molecules in a cracking still, the same identical thing may happen when you maltreat the fuel in a gas engine. I want you to keep this specifically in mind because heat and pressure have about the same effect regardless of where they happen to be, in a gas engine or in some other place.

I want to impress upon you another very important fact. If you take the heat of a pound of carbon and the heat of a pound of hydrogen, you will find, if you burn the gas CH_4 mentioned above, that you will not get the same amount of heat from this gas as you would expect if you added up the heat contained in the corresponding

Digitized by Google

amounts of carbon and of hydrogen. It will always be somewhat less. This apparent loss in heat value is a result of what is known as energy of combination and enters largely into the study of chemical compounds. I want to impress on you the fact that each of these compounds has a certain heat value which is always less than the total heat value of an equal quantity of carbon and hydrogen in an uncombined state.

Specific Gravity of Fuels

The question of gravity and the size of a molecule is a very interesting thing. If we start with the simplest compound of the paraffin series, CH_4, and add carbon and hydrogen atoms to it, one of carbon and two of hydrogen at a time, we find that the first few compounds are normally a very light gas and extremely difficult to liquefy. As we come down the line, we find that the compounds would become normally liquid, and finally solid, in form. Carbon has an atomic weight of twelve and hydrogen of one, so that CH_4 has a weight of sixteen. As these compounds increase by CH_2 each time, which means an increase of fourteen in the molecular weights for each compound, it is quite obvious that the molecular weights will mount up rather fast. It is easy to see that these are actually physical things. There has always been one trouble with all of our theoretical work. We take up this molecule as though it were simply something to think about and to talk about. But these are real physical things and the combination and decomposition of these things are real physical facts. I think that if we all could get the point of view that this is not complex at all, and we could get somebody to write a chemistry that would make it appear simple instead of complex, we would all get interested in this and be able to do much good by actually studying the fundamental phenomena.

As I mentioned before, the more carbon atoms we get into the compounds, the heavier the fuel becomes. It was for this reason that we, a long time ago, began to measure our fuel by hydrometers. If it measured 72 deg. it was fine. Finally it began to go down and down, and we tried to force upon our oil people the idea that gravity had something to do with a fuel's desirability. Now gravity has not a thing to do with it.

Suppose we started a food law in this country that we had to sell potatoes not by the bushel or by the pound, but that there must be so many potatoes to the

Digitized by Google

bushel, and that they must have an average weight per bushel. This is actually what we asked the fuel people to do. Suppose the food inspector comes around and examines a bushel of potatoes. He counts the potatoes and says, "There are not enough"; so he takes out one big potato and puts in a couple of small ones and the potatoes are O K'd by him. Then, after the potatoes are sold, they are placed in a pan and put into an oven to bake. And if we leave them in there for an hour, the little potatoes are burned to a crisp and the big ones are not cooked through. Exactly the same thing happens with fuel. There is no difference whatsoever. The average of our fuel may be all right, but that does not mean that we have anything like a good fuel.

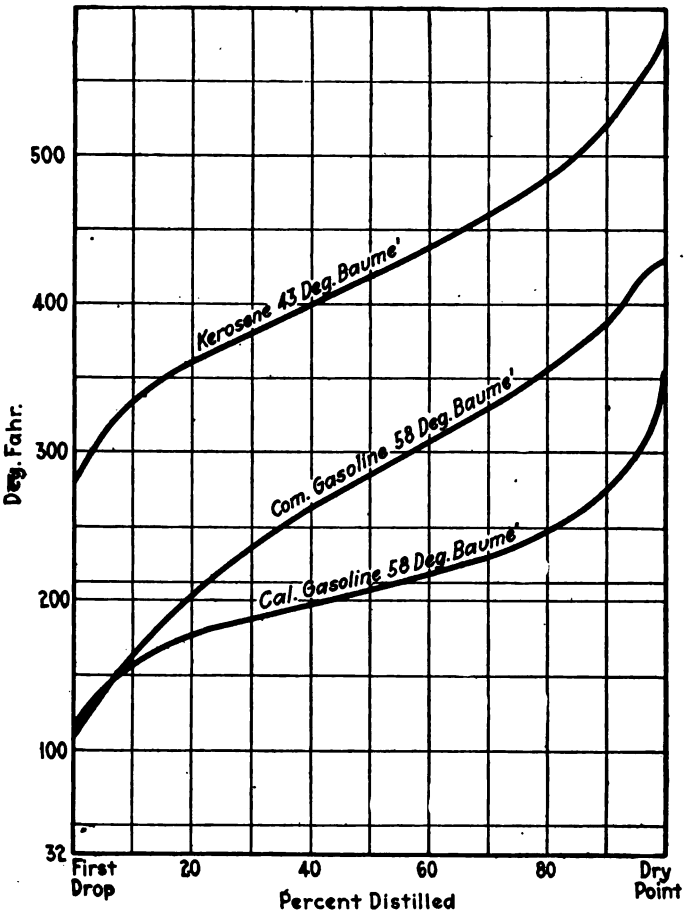
Distillation curves have come to be a measure of fuel suitability. They are of a great deal more importance than its gravity. I have had charts showing certain distillation curves prepared. In the chart there is shown a kerosene curve. This kerosene had a gravity of 43 deg, and it started to distill off at about 275 deg. fahr., the percentage evaporated increasing with continued heating and a rising temperature until it finally goes dry at 600 deg. fahr. This is a characteristic curve. This chart also shows commercial gasoline having a gravity of about 58. It shows, in addition, a very interesting and significant fact. When the curve of a California gasoline of 58 gravity is compared with the curve of this other gasoline of 58 gravity, it is seen that the California gasoline has a considerably flatter curve. The reason for this I will show later. We all know that there have been developed in California many wonderful kerosene carbureters which were sent to us here in the East, but which, when put on our engines, failed signally to live up to the claims made for them. This is easily explained. The fact is, California kerosene is often a great deal better than our gasoline, so far as carburetion is concerned.

Benzol and Alcohol as Fuel

In addition to the types of hydrogen and carbon compounds already discussed, which, because of the arrangement of the atoms therein, are called "chain" compounds, there are certain other hydrogen and carbon combinations called "ring" compounds. One of the simplest and probably the best known of these is benzol. In this there are six carbon atoms, with three single and three double bonds connecting them, each carbon atom

Digitized by Google

having a single hydrogen atom attached to it. The formula for this compound is C_6H_6. As you no doubt remember, when Mr. Crane was discussing his paper on Possible Effect of Aircraft Engine Development on Automobile Practice he mentioned the fact that by the addition



DISTILLATION CURVES OF VARIOUS INTERNAL-COMBUSTION ENGINE FUELS

of a certain amount of benzol to a fuel, certain very interesting results are obtained. That does not of itself mean that benzol will necessarily make a good fuel, because there happen to be other considerations involved.

Digitized by Google

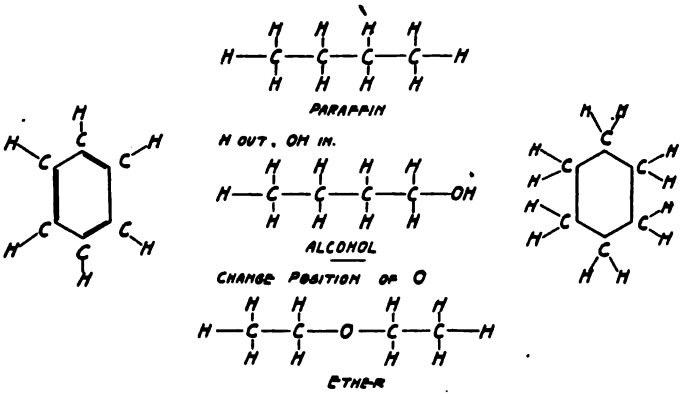
If we run benzol on full load it gives satisfactory results. It is so high in carbon as compared with the amount of hydrogen that if we do not run it on full load very copious productions of carbon in the engine result. This carbon, however, is quite different in character from the carbon which results from the burning of kerosene. It is a fine, fluffy or flaky deposit, not at all gummy or sticky like a kerosene carbon deposit and is blown out readily in the engine exhaust. It does carbonize the spark-plugs badly, however, and will interfere seriously with the running of the engine.

An interesting thing about this type of fuel is that all of the "potatoes" are exactly the same size. The benzol distillation curve represents a mixture of certain of these uniformly sized "potatoes," and we can see what happens. After we get up to a certain temperature, the fuel begins to distill off and practically all of the fuel goes off at that temperature. In other words, all the molecules weigh the same and they all get out at the same time. At the very end of the distillation curve the end point goes up rapidly. A fuel having this characteristic may or may not have desirable characteristics from the standpoint of distribution, but its functioning after it once gets into the engine may be of an entirely different order from the functioning of another fuel having a corresponding gravity. This fuel may be of much lower gravity than another type and yet function very much better under combustion conditions within a cylinder. The gravity of a fuel has absolutely nothing to do with what the fuel really is, or how it performs in service. The main point I want to present is that the fuel proposition, so far as future engine design is concerned, is practically a question of chemical construction and make-up, together with energy of combination that exists within the fuel itself.

There is still another illustration of the fact that the chemical formula does not mean anything. If we take benzol and break the double bonds existing in the benzol ring and add a hydrogen atom to each carbon atom we will get a compound having the formula C_6H_{12}, which represents a certain thing and a certain specific gravity.

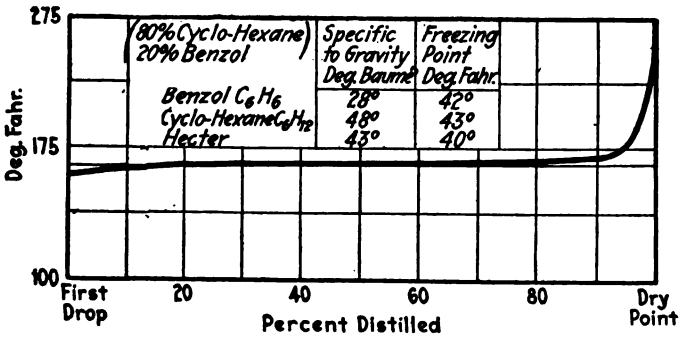
We have heard a great deal of discussion about alcohol. The formula is $C_nH_{2n+2}O$; but that is not a very good way to write it. It is better to write it in the manner illustrated herewith. If we take a "chain" compound of the structure shown there and trade the hydrogen atom

Digitized by Google



TYPICAL "RING" AND "CHAIN" HYDROCARBON COMPOUNDS AND THE CHANGES PRODUCED BY VARYING THE RELATIVE POSITIONS OF THE DIFFERENT ATOMS

for a hydrogen and oxygen atom, we get a compound having the structure shown there as alcohol. That hydrogen substitution is the only difference between paraffins and alcohol. The paraffin compound has a certain gravity and will function in a certain way. The alcohol corresponding thereto has a certain gravity and functions in a certain way. The fuel value of these two compounds following the substitution of OH for H is quite different. The alcohol does not burn the same way or act the same way. We have the same amount of carbon in each and practically the same amount of hydrogen, but we have an oxygen atom hooked up in connection with one of the hydrogen atoms. Investigation will show that it takes practically one-half the total amount of heat



DISTILLATION CURVE OF BENZOL

Digitized by Google

available in the fuel to get an oxygen atom into the compound, and yet consideration of the actual atoms within the compound would tend to show that it should have about the same amount of heat as before the change occurred.

Suppose we take the alcohol illustrated and use exactly the same atoms, but simply shift the arrangement of them a little, so that the oxygen is connected to two carbon atoms and not directly to any hydrogen atoms as shown; in this case we have the hydrogen atoms in the same place and the carbon atoms in the same place, except with relation to the oxygen atom, but we now have ether instead of alcohol. The two have exactly the same composition so far as the number of atoms is concerned; so that the chemical formula, if merely written out, would be exactly the same thing, $C_4H_{10}O$. If we bought alcohol according to chemical formula, we might easily make a mistake and put ourselves permanently to sleep. Also, performance in an engine is entirely different. The gravity of these two is practically the same, but the boiling point of the ether shown is 95 deg. fahr., while that of the alcohol shown is about 243 deg. fahr. Inasmuch as they have exactly the same chemical formula, it is obviously of great importance to know something about their structure and make-up, to determine performance as fuel. If we refine our shale oils, and are going to make the right kind of engine to run on such oils, we have to know what kind of business relationship the atoms have gone into with each other before we can handle the oils properly.

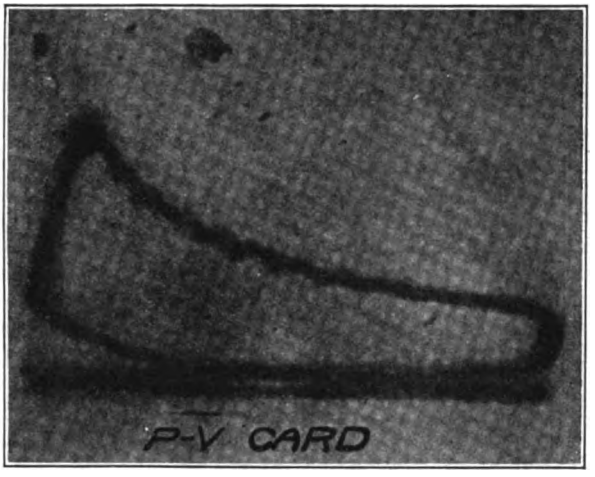
Cylinder Knocks

I have mentioned energy of combination because to us it has proved very, very interesting, inasmuch as it apparently affects fuel action very directly. As I said before, as fuels of lower gravity came into use it became necessary to lower compressions. The general idea has been that this lowering of compressions has been necessary because of preignition. To study this problem we developed an indicator which gave us a new but very satisfactory type of indicator card. This indicator is different in that it gives pressure-time indications and not pressure-volume. As a result of our work with this indicator, we discovered that the knock which comes from kerosene is an entirely different thing from actual preignition. We have made hundreds of indicator diagrams

Digitized by Google

or cards with this instrument and each of them is very different from the usual pressure-volume card secured with the ordinary indicator.

A card made with our indicator is also shown illustrating the normal burn in an engine cylinder, without any evidence of a knock. As you can see from this card, pressures begin to go up at the instant the compression stroke of the piston is started and increase uniformly until ignition, after which pressures go up rapidly to a maximum and then taper off gradually during the work



A Typical Pressure-Volume Card Secured from an Internal-Combustion Engine

stroke of the piston. The difference between the cards made on these two types of indicator is quite obvious and needs no explanation.

Another card made with our indicator and illustrating a case of true preignition is reproduced. The kerosene knock occurs in a region of from 10 deg. after ignition to 25 deg. past top center on the down stroke. In one card shown, the knock occurs fairly early in the combustion stroke, while in another its occurs at approximately 25 deg. after top center and on the down stroke of the piston.

These cards proved tremendously interesting to us and we began to study the knock to see what it is and why it is. In the course of our study we have been theorizing

Digitized by Google

and reached the following conclusion. If we take a complex molecule and start to burn it, it will not burn by a single step from the carbon and hydrogen in it to carbon dioxide and water, but as it starts to break down it may be decomposed into a variety of compounds. If during this burning we should happen to liberate, for an instant, as intermediate products of combustion, some compounds of an extremely explosive or detonable nature, we would, upon explosion of these compounds, get such a sudden rise in pressure as is indicated in the cards shown. Now the compounds which form, if these big molecules do break down in this way, will differ, depending upon the temperature and pressure conditions at the time combustion takes place. That is, the type of compounds which are formed will vary with the compression, explosion pressures and the temperatures which exist in the cylinders.

In studying the conditions existent within the cylinder during knocking we endeavored to get an actual view of conditions within the cylinder at the time the knocking took place. To do this we put a window in the cylinder and pointed a spectroscope at this window. In this way we were able to reach some rather definite ideas as to the substances or compounds actually present and causing the knock. As a result of these observations we came to the conclusion that the compound which caused the trouble is acetylene. I will admit that this is one of the things that we have only theorized about so far and that we do not know now that this is really true.

What takes place within a cylinder when the knock occurs may readily be in accordance with my previously mentioned conception. You have all seen the grains of powder used in big guns. It comes in little sticks with perforations through them. Now you can take one of these sticks and light it with a match and hold it in your hand as it burns and it is perfectly harmless. But if you stuff that powder into an iron pipe and screw the end on it and light it, and then get away in time, you would witness quite a different reaction. The reason is that when you vary the pressure and temperature conditions you change the entire nature of the burn. In other words, in the first case you are simply burning the stick of powder as you would any other inflammable hydrocarbon, while in the second case you are releasing its energy of combination in a very short space of time. The resulting variation in the chemical reaction which

Digitized by Google

takes place causes the sudden building up of pressure that we call an explosion.

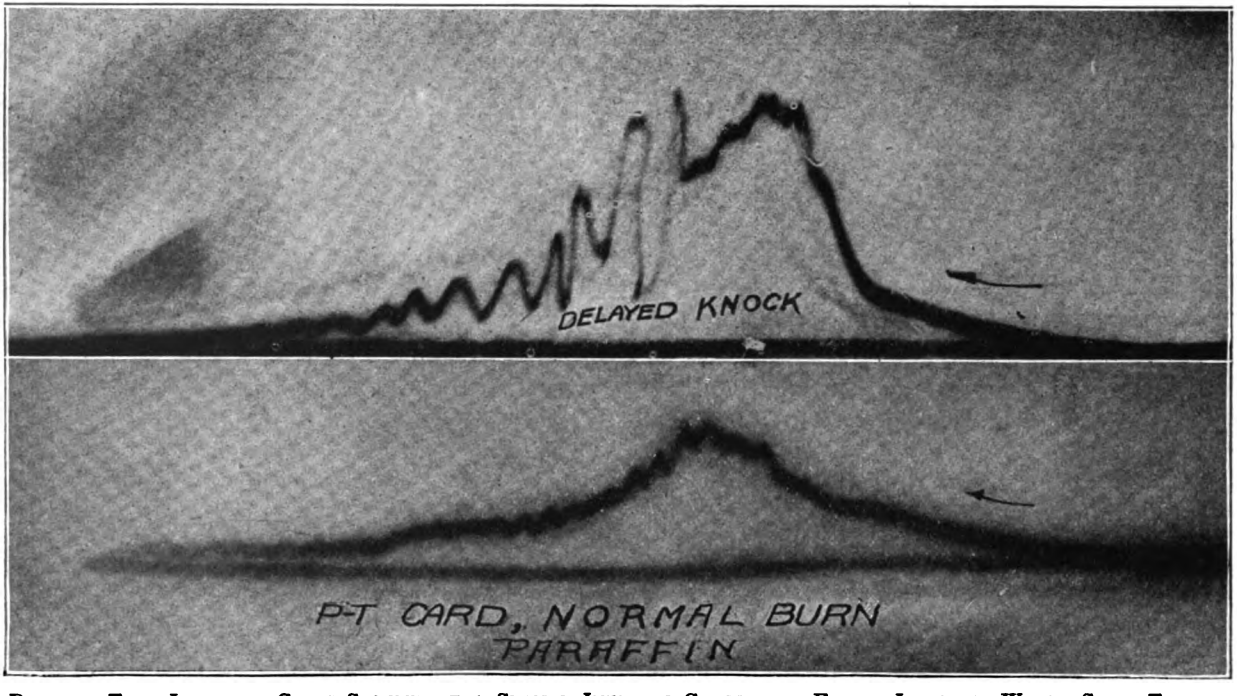
If our idea of the formation of secondary compounds is a true one, then if a fuel can be found which will burn by a single step from carbon to carbon dioxide and from hydrogen to water, it should be a fuel which does not give a knock. We started out by taking benzol. But we found that it was not a satisfactory fuel because of its free liberation of carbon upon burning. So we took this benzol and broke the double bonds between some of the carbon atoms and hitched on an extra hydrogen atom to each carbon atom, so that instead of being C_6H_6 it became C_6H_{12}. This, of course, made a material difference in the gravity of the fuel. And, incidentally, I might state that the gravity of benzol is only 28 deg., so that if a man were buying it by gravity he would imagine himself to be getting a very poor fuel. The gravity of C_6H_{12}, the name of which is cyclohexane, is 48 deg.

Tests of Cyclohexane

Now here is the interesting thing about this cyclohexane. When we made it up and used it in an engine it acted differently from any fuel we had ever had. It took a long time for it to sink into our heads, but finally this fact came home to us: if a fuel burns by a single step from carbon to carbon dioxide and from hydrogen to water, the explosion will be absolutely independent of the compression, because the temperatures and pressures can only rise to such points in the cylinder as the products of combustion permit. That is, the temperatures of combustion cannot rise above the dissociation temperature of the products which result from such combustion. Consequently, when this fuel is used in an engine cylinder we get a pressure-volume card that looks like a steam-engine curve. And we can, without materially raising the explosion pressures, run this fuel on any compression up to the point of actual preignition, caused by the temperature rise due to compression reaching the ignition temperature of the fuel. This brief outline of our work with this fuel seems to indicate that the knock is certainly due to the formation of secondary or intermediate combustion compounds, detonatable compounds we call them, which let go unexpectedly and cause an abnormal rise of pressure.

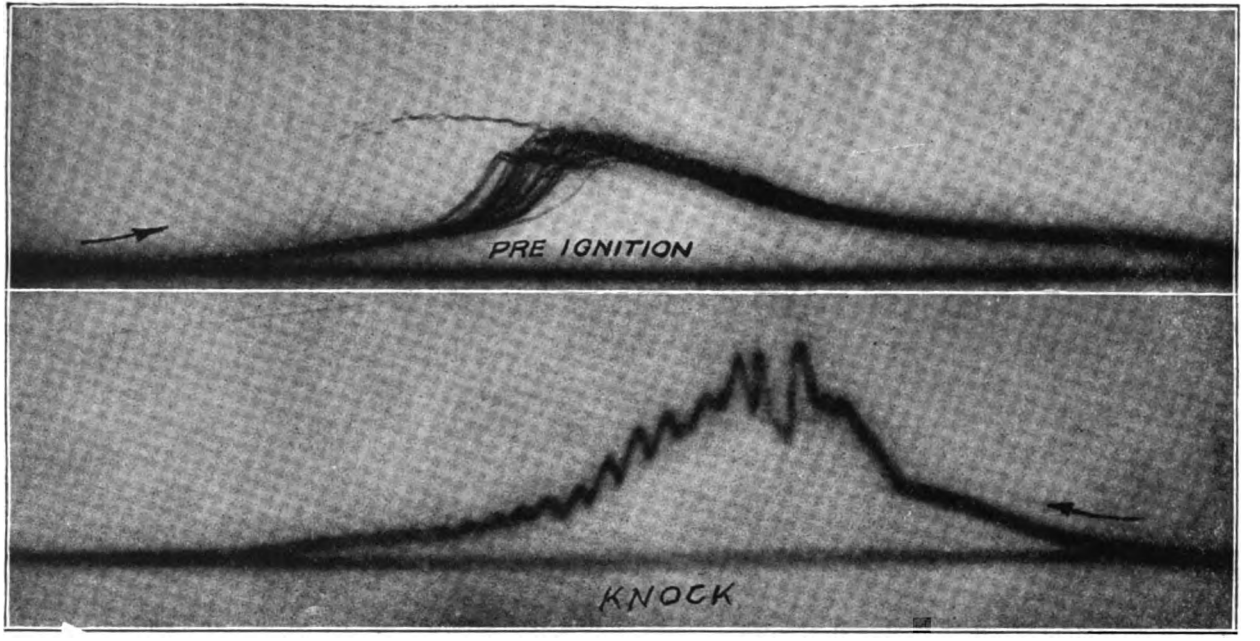
Why then should lowering of compression prevent the development of the knock? Simply because lowering the

Digitized by Google



PRESSURE-TIME INDICATOR CARDS SECURED BY A SPECIAL INTERNAL-COMBUSTION ENGINE INDICATOR WHICH SHOW TYPICAL OPERATING CONDITIONS

Digitized by Google



PRESSURE-TIME INDICATOR CARDS SECURED BY A SPECIAL INTERNAL-COMBUSTION ENGINE INDICATOR WHICH SHOW TYPICAL OPERATING CONDITIONS

Digitized by Google

compression results in a substantial lowering of the maximum combustion temperature within the engine cylinder.

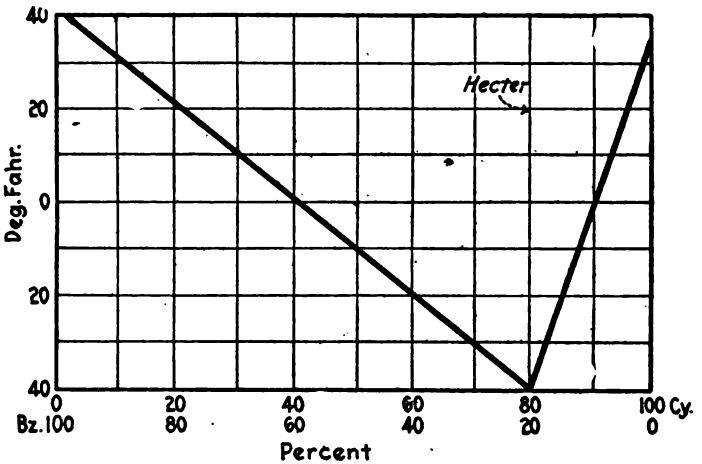
For testing cyclohexane we built a Liberty engine having 200-lb. compression, and this fuel burned at such high compressions without any knock whatever. With the best grades of gasoline that we could secure we could not use compressions in excess of 125 lb.; in fact, without very careful selection of gasoline the compression could not be run up to more than 100 lb.

There is another interesting thing leading us to believe that there is a critical temperature beyond which we cannot go without causing an entirely different type of combustion to take place in the engine. If we take an engine operating at 75 to 80-lb. compression, start to run it on kerosene and let it warm up, there will be no knock during this warming-up period. As soon as the engine gets up to operating temperature, however, it will start to knock, and it will immediately heat up, with loss of power and other evidences of poor performance. However, if we introduce into the fuel that is being used 3 or 4 per cent of ethyl iodide, we can run the same engine right up to full compression without knocking and accompanying troubles. In other words, the engine will run as well as it does on gasoline. The reason for this is, we think, that below 1200 deg. fahr. iodine exists in the form of molecular vapor, but between 1200 and 2000 deg. fahr. the iodine vapor breaks part into an atomic vapor and in so doing uses up a considerable quantity of the heat energy resulting from the combustion within the cylinder. And the heat energy so used up will just ease off the temperature curve, flatten it out, in other words, and hold the maximum temperature below the critical line so that the secondary explosive compounds will not be formed.

There are a great many interesting phases and peculiar things in connection with the fuel game. My idea has been to present this subject to you more as a means of stirring up your interest and exciting your curiosity than supplying any fundamental engineering data. As an example of one of these interesting things, we found, when we investigated cyclohexane, that it would freeze at 42 deg. fahr. We also found that benzol freezes at 43 deg. fahr. Consequently, neither of these compounds of itself would make a satisfactory fuel, especially for airplane work where temperatures considerably below the

Digitized by Google

freezing point of each fuel are prevalent. We found out this very interesting thing, however. If we take some cyclohexane and some benzol and mix them, the freezing point of the mixture is considerably below that of either constituent. By mixing them in the proportion of substantially 20 per cent benzol and 80 per cent cyclohexane, we get a freezing point for the mixture of substantially 40 deg. below zero, fahr. If it were not for the facts in connection with this statement I know you would not believe that if two fuel compounds are taken, each one of which freezes at a comparatively high temperature, and are mixed together in certain proportions, the freez-



MIXING BENZOL AND CYCLOHEXANE REDUCES THE FREEZING POINT OF THE MIXTURE MATERIALLY AS COMPARED WITH THOSE OF THE CONSTITUENTS

ing point of the mixture can be reduced 80 deg. It is simply another case of molecular energy making such a thing possible.

I might go on into various interesting experimental data, but there are one or two other things that I want to bring out. We have all talked about carbon causing the knock in an engine and we know that when we clean the engine out we do not get the knock any more. And we have all had the idea that the reason we have carbon knocks is because some of the carbon heats up and preignites the incoming mixture. That is not what happens at all. One of the best heat insulators we have is

Digitized by Google

carbon, and the only thing we do when there is a nice little carbon deposit in a gas-engine cylinder is to cut down the rate of thermal transfer.

Securing Better Engine Efficiency

One of our big problems in connection with fuels, therefore, seems to be to discover how to lower the temperature peak during combustion. We must remember, however, what happens when a cylinder is cooled too much. The crankcase gets filled up with anything but oil. The big problem then seems to be to get a more efficient regulation of temperatures. And we must make this a problem whether we desire it or not. The factors governing the supply of fuels are now such that we must take our present grade of fuel whether we want to or not. Consequently, we must study the relationship and the conditions which exist after we get the fuel inside the engine cylinder. No matter what the fuel manufacturers hand us, or where it comes from, we have to take it and burn it, and give satisfaction to the customers using it. None of us believes that the internal-combustion engine business is going to die out because we are having difficulty with fuel. But the amount of satisfaction the users of the engine will get is going to be proportional to the enthusiasm, pep, chemical knowledge, etc., that the engineer puts into the engine before he turns it out.

So I think it is only well at this time that we should begin to think in terms of the fuel question, not only from a supply and demand point of view, but also from an efficiency standpoint. We engineers have a lot to do from the latter standpoint; we have hardly touched the subject as yet. The ordinary engine running around the streets of New York has a thermal efficiency of from 5 to 10 per cent. We must make it higher. In our own work we have run some common ordinary engines up to 29 per cent thermal efficiency, and this without any very great amount of work on them. This leads us to believe that there is a possibility of going far beyond the range of our ordinarily prescribed limit of 25 to 30 per cent. I think that in 5 or 10 yr. from now it will be common practice to secure in the neighborhood of 35 or 40 per cent thermal efficiency.

Remember that a problem is what we think it is. If we think an engine can run only 10 hr. without repair it will run just that length of time. If we think it can

Digitized by Google

run 100 hr., the chances are it will. If there is any one thing the war has demonstrated to us, it is that we have not exhausted anything like the mechanical possibilities of any device. Anything that man creates is only a physical representation of his mental conception of it. If some one should come here from some other world he would get a very bad idea of the mental conception of our automotive engineers, if they do not get busy on the little simple problems of settling this fuel question. In this talk I have shown where I think the problem lies. No matter what kind of injection devices or other instruments we may have, there is the problem of finding out how the fuel acts after it is inside the cylinder, and we must work out this problem. And this problem can never be solved by any one individual. It is going to be solved by cooperation between the oil and the engine people and every one else.

Digitized by Google

THE UNMINED SUPPLY OF PETROLEUM IN THE UNITED STATES[1]

By David White[2]

PRODUCTION records show that the United States oil fields have produced approximately 4,600,000,000 bbl. since 1858, the present rate of annual production being approximately 350,000,000 bbl. On the other hand, the oil remaining available in the ground is estimated by the oil geologists of the U. S. Geological Survey at 6,740,000,000 bbl., about half of which belongs to the heavier grades. This estimate is distinctly conservative, but the amount eventually recovered should not very greatly exceed it. With an annual consumption now reaching 400,000,000 bbl., the remaining oil would not last many years if it could be discovered and mined as fast as required. However, this cannot be done; many pools will not be located within twenty years, and the curve of waning oil production will probably continue for as long as seventy-five years.

The danger to the country's welfare and prosperity lies in the rapidly increasing consumption without restriction of use, promising to exceed one-half billion barrels yearly within a few years, and in the fact that, with most vigorous efforts, we are able only slightly to increase production, which almost certainly will pass its peak and enter the period of decline at an early date, probably within five and possibly within two years. Meanwhile, storage supplies are being exhausted and oil is imported in increasing amounts to meet requirements. Present monthly imports averaging about 4,000,000 bbl. must be expanded to enormous volume when our domestic production declines, unless the now soaring consumption is correspondingly reduced, which is not to be thought of. American oil companies must protect the future by acquiring great and widespread foreign oil concessions.

Oil in vast amounts can be artificially made from the great oil-shale deposits of the West, but the processes and prices necessary to commercial success remain to be determined, and the task of building up an oil-shale industry sufficient to meet a considerable part of the demand is enormous, requiring several years.

The justification of an estimate so highly speculative as must be that of the petroleum resources in

[1]Published by permission of the Director of the U. S. Geological Survey.
[2]Chief geologist, U. S. Geological Survey.

Digitized by Google

the ground in the United States, lies in the widening angle between the flattening curve of production and the rising curve of consumption. The standards of living, the industrial power and the prosperity of the country are dependent to so great a degree upon our oil supply, and the question of the adequacy and duration of this supply so directly concerns the individual citizen and the general public, at present, that an estimate is imperatively necessary, even if it be but a scientific guess, based, with careful study, experience and judgment on the best information available.

In response to the growing interest of the public, four estimates of the oil resources of the United States have been made. In 1908 Dr. David T. Day,[3] then in charge of petroleum statistics in the U. S. Geological Survey, calculated the total amount of oil originally available in the ground as ranging somewhere between a minimum of 10,000,000,000 and a maximum of 24,500,000,000 bbl. In 1915 Dr. Ralph Arnold[4] placed the original supply of oil at 9,098,557,000 bbl., of which he believed 5,763,100,000 bbl. remained in the ground at the end of 1914. The third estimate was made by the geologists of the oil and gas section of the Geological Survey for the use of the Secretary of the Interior in responding to a Senate resolution of Jan. 5, 1916, and was published in Senate Document 310, Sixty-fourth Congress, first session, Feb. 2, 1916. According to this estimate the reserve of oil available at the end of 1915 was 7,629,000,000 bbl. In the spring of 1917 the production records and the possible oil regions were closely reconsidered with marked conservatism by the same geologists, each studying the regions with which he had field acquaintance, with the result that the total oil available in the ground at that time was estimated at 6,182,000,000 bbl.

In the preparation of estimates by the U. S. Geological Survey consideration has been given to the general character of the geologic formations—stratigraphy, geologic history, structure—the number, thickness, continuity and pore space of sands, the curves of production, the gas pressure, the water relations, and the results of drilling in near-by or geologically similar regions. A large part of the producing or possibly productive area in the Western States has been examined and mapped by the oil and gas geologists of the Survey or is now under examination.

[3]U. S. Geological Survey Bulletin, No. 394, 1909, page 30.
[4]*Economic Geology*, vol. 10, No. 8, page 695, December, 1915.

Digitized by Google

Typical areas in the Central, Gulf and Eastern States have also been studied. Nevertheless, the criteria upon which estimates can be based vary in every degree of inadequacy in the different regions, and the quality of the results, therefore, varies with the extent and character of the data available and with the personal equation of the estimators. Necessarily the estimates for areas not yet tested, especially those remote from the producing fields, are based upon theoretical conditions, carefully considered. For most of the areas estimates were first formulated by the geologists who had studied the areas. Later, these estimates were discussed in conferences.

Recent Geologic Investigations

Further recent geologic investigations in the field and the study of the results of testing and exploration, especially in the Rocky Mountain and Gulf States, have furnished the basis for a more reliable recalculation of the estimates for a number of the regions. The conclusion reached is that the available oil in the ground at the end of 1918 approximates 6,740,000,000 bbl.

The new estimates, combined according to the commercial fields, are given in the accompanying table, in which for comparison and information are shown the marketed production for 1917 and the estimated output for 1918, as compiled by John D. Northrop of the Geological Survey in charge of statistics of petroleum and natural gas, and the approximate total production of petroleum in the United States to the end of 1918, also based on Geological Survey records. For the immediate convenience of the reader there is also included the percentages of average gasoline recovery from the oils of the different fields at the present time. For the latter data the writer is indebted to Chester Naramore of the Bureau of Mines, in which bureau the returns of gasoline recovery from the oil runs are compiled. The general characteristics of the various crude oils in the different fields are too well known to require discussion in this paper, and their especial qualities will be fully considered in those to follow. It will, however, be noted that the reserves of the heavy oils of California and the Gulf coast are estimated at about 3,000,000,000 bbl. Probably such low-gasoline oils comprise more than one-half of the total reserves.

Those who have followed the history of petroleum in America and understand how much of our present-day oil-

Digitized by Google

field development has taken place since Day made his estimates in 1908 and even since Arnold calculated the reserves in 1915 will appreciate the great advantages, mainly in the form of results of exploration and records of production, enjoyed by those who make computations now. However, with these circumstances in mind, we may, nevertheless, for comparison, compensate and bring to date the earlier estimates by deducting subsequent production to the end of 1918. The available oil in the ground at present would be, according to these estimates, as follows:

Day (estimate in 1908), 5,402,000,000 to 19,902,000,000 bbl.

Arnold (estimate in 1915), 4,500,000,000 bbl.

Geological Survey (estimate in 1916), 6,647,000,000 bbl.

Geological Survey (estimate in January, 1919), 6,740,000,000 bbl.

The recent estimate by the Geological Survey as given above and as differentiated by fields in the accompanying table, differs from that of 1916 mainly in a more conservative view as to prospects in Montana and recoveries along the Gulf coast and in a more optimistic attitude toward Kansas and the States of little or no present production. As compared with the very conservative estimate formulated in the Geological Survey in 1917, they represent greater confidence in Wyoming, north Texas, Alaska and several minor States. In general, they are to be regarded as conservative, and there is little probability that the actual yield will fall short of the calculated amounts. They are, however, likely to be again revised in the near future, as the modes of occurrence of oil and gas in different regions become more fully understood, as exploration proceeds, and as the areas offering possibilities of oil discoveries are examined more in detail.

The reports of production of petroleum in the United States, as compiled by the Division of Mineral Resources of the Geological Survey, show that since 1858 approximately 4,598,000,000 bbl. of petroleum has been taken from the ground. This is more than two-thirds as much as remains available according to the latest estimate by the Geological Survey, and exceeds what would now be left according to Arnold. Further, the oil companies are now taking out over one-third of a billion barrels a year.

Digitized by Google

AVAILABLE OIL REMAINING IN GROUND, AS ESTIMATED BY THE U. S. GEOLOGICAL SURVEY
(Bbl. of 42 gal.)

Oil fields	Marketed production in 1917	Marketed production in 1918 (preliminary estimate)	Total marketed production to end of 1918	Available oil left in ground, January, 1919	Present average gasoline extraction, per cent
Appalachian	24,932,205	25,300,000	1,221,737,000	550,000,000	28.0
Lima, Indiana	3,670,293	3,100,000	448,404,000	40,000,000	20.0
Illinois	15,776,860	13,300,000	298,159,000	175,000,000	22.0
Mid-Continent	144,043,596	139,600,000	990,573,000	1,725,000,000	24.0
North Texas	10,900,646	15,600,000	78,971,000	400,000,000	33.0
North Louisiana	8,561,963	13,000,000	90,902,000	100,000,000	28.0
Gulf	24,342,879	21,700,000	303,954,000	750,000,000	1.5
Wyoming	8,978,680	12,370,000	39,793,000	400,000,000	40-50
California	93,877,549	101,300,000	1,114,000,000	2,250,000,000	12.0
Alaska, Colorado, Michigan, Montana, etc.	230,930	230,000	10,651,000	350,000,000	....
Total	335,315,601	345,500,000	4,598,144,000	6,740,000,000	....

Digitized by Google

Relation of Production and Consumption

The situation as to petroleum production and the importance of the remaining oil resources of the United States are both graphically indicated by the curves in the accompanying chart. The most significant features here shown are the steep ascent of the consumption curve and the flattening, in 1918, of the curve of actual production in spite of the vigorous efforts of the oil companies to increase their war-time output even at the expense of their proved reserves. To fill the gap between our actual domestic production and the requirements of domestic consumption it has been necessary to reduce the

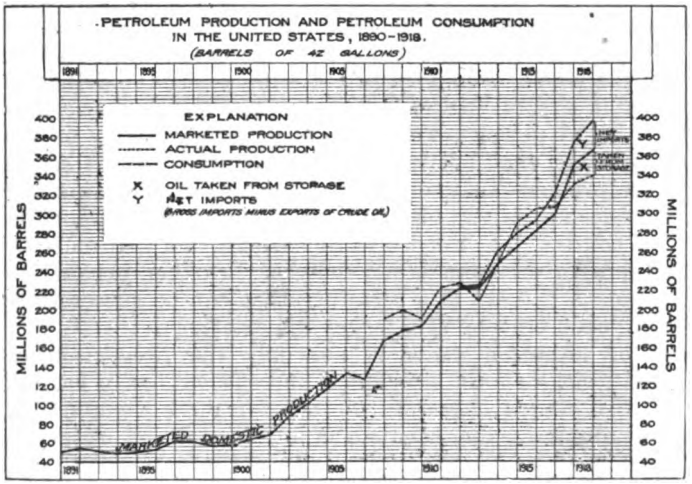


Chart Giving the Relations Between the Production and Consumption of Petroleum in the United States for the Past 28 Years

oil in storage to the extent of 27,000,000 bbl. and to supplement this with a net importation of 31,000,000 bbl., chiefly from Mexico. The deficiency of our current production during 1918 has, therefore, amounted to 58,000,000 bbl., nearly half of which has been withdrawn from storage. That is to say, this country has to the extent of 27,000,000 bbl. of storage oil been living on its reserve, which is now reduced to about 123,000,000 bbl.

According to general expectations, barring disaster, shortage of supply, or much higher prices that might result from such shortage, the consumption curve is destined, during the next year and probably longer, to con-

Digitized by Google

tinue its present general trend beyond the 400,000,000-bbl. mark, which it nearly reached (397,000,000 bbl.) in 1918. On the other hand, whether the domestic production can be increased in volume to correspond to the consumption remains to be seen. Glenn pools and Cushings may await discovery, but the strike of a Glenn pool such as produced the bulge in the storage curve for 1907 and 1908, or of new Healdtons and Cushings, such as were largely responsible for the production swell of 1914-15, will make a less conspicuous wave in the greatly expanded and diffused production of today. Texas, the Osage country and Wyoming will furnish notable contributions, but so many fields are now running down that it will require numerous successive strikes of large magnitude to send the production curve so high that oil will go into storage without considerably increased importations. On the whole, even with prices stimulating the driller to greater efforts, it seems unlikely that the domestic production of petroleum can at best gain appreciably on the reasonably expected increase in consumption. It seems more probable that, unless consumption is restrained by high costs, the gap between consumption and production will continue to widen. In any event, this gap must be filled with oil from other sources. Further exhaustion of stocks in 1919 is a certainty that can be successfully minimized only by still larger importations.

The situation demands not only the prevention of waste, but the most economical and efficient use of our oil. Also, it warns operators to consider more thoughtfully and promptly the acquisition of foreign oil reserves. Mexico, to which the American public looks with optimistically hopeful eyes, probably contains less oil—perhaps very much less—than remains in the ground in the United States.

How long the commercial production of natural petroleum will continue in this country is a question whose answer is no less speculative than the quantitative estimates. After the production peak is passed, be it 1 year or 5, the annual output of natural oil will decline gradually for a long time. Oil wells will be producing at least 75 years hence. The pools cannot all be so soon discovered; the oil cannot immediately be got out of the ground. The discovery of deep sands is likely to give new life to many old or even abandoned fields. Pools will be found after prolonged search and repeated wildcatting in old as well as new regions, and this is probably especially

Digitized by Google

true of the Gulf coast, where, unless geologic discovery and consequent new methods of search come to the aid of the driller, it may be 75 years before some of the productive salt domes are revealed.

The most significant feature of the prospect, however, is the probability that, although an estimated two-thirds of our reserve is still in the ground, with an annual drain of one-third of a billion barrels, the peak of production will soon be passed, possibly within 3 years. The date when the peak will be reached is a matter of individual opinion, in which predictions have wide range. There are many well-informed geologists and engineers who believe the peak in the production of natural petroleum in this country will be reached by 1921 and who present impressive evidence that it may come even before 1920.

Development of Oil Shale

In her deposits of oil shale the United States has an anchor to windward. Oil shale is a richly bituminous shale, some of it approaching cannel in character, interbedded, like coal, in series of shales, sandstones and limestones. The most extensive and valuable deposits known in America if not in the whole world are in northwestern Colorado, northeastern Utah, and southwestern Wyoming, mainly in what is known as the Uinta Basin. Rich beds of oil shale also occur in very limited areas in northeastern Nevada. Minor deposits, more conveniently located but for the most part leaner and less promising, are found in the Mississippi Valley and the Appalachian States. D. E. Winchester[5] and A. R. Schultz, of the Geological Survey, have estimated that there are in Colorado, Utah, Wyoming and Nevada deposits of oil shale in thicknesses of 3 ft. or more, and capable of yielding 25 gal. or more of oil per ton, sufficient to produce at least 75,000,000,000 bbl. of oil.

The oil is generated through the destructive distillation of the shale, and its character and composition depend largely on the processes employed. Rough dry or steam distillation tests produce distillates, essentially heavy petroleums, carrying both paraffin and asphalt with considerable nitrogen and yielding gasoline in an average of about 12 per cent. These rough tests indicate that the

[5]U. S. Geological Survey Bulletin No. 641-F, 1917; Bulletin No. 691-B, 1918.

Digitized by Google

gasoline obtainable by distillation of these shales, even by simple methods, far exceed in amount all the petroleum yet produced in the United States and may equal the remaining natural oil.

The production of oil from these shales is still in the experimental stage, in which various methods are being tested. Much doubtless depends on the processes devised and adopted. It is possible that initial commercial success may be determined as much by a study of methods and of the possible by-products and their values as by a further advance in oil prices. The technologic problems connected with the utilization of the oil shales are worthy of research by the best hydrocarbon engineers and chemists.

Shale oil is the most natural, satisfactory and ample substitute for petroleum, and it is likely to come into the market as the production curve of the natural oil glides downward beyond the peak, if not sooner. It must be borne in mind, however, that in spite of the probable very rapid growth of the shale-oil industry, beginning with the day that shale oil is produced profitably on a commercial scale, it will require several years to construct and put into operation the enormous plants necessary to treat the millions of tons of shale which must be distilled in order to offset the waning production of natural oil, or fill a part of the gap between the production and consumption of petroleum in the United States.

Digitized by Google

STATUS OF REFINERY PRACTICE WITH REGARD TO GASOLINE PRODUCTION[1]

By Dr E W Dean[2]

THE production of gasoline in this country could be increased through the following changes in refinery practice:

(1) Universal adoption of a high "end-point," or upper volatility limit for gasoline
(2) General use of more efficient distillation methods and equipment
(3) Recovery of gasoline now lost in refinery operation
(4) Wider use of cracking processes

Other possible methods of increase are not considered of sufficient importance to merit discussion in this connection. Some of the details of the four methods of increase are discussed and it is estimated on the basis of the evidence now at hand that the maximum percentage increases in production under the four heads listed are as follows: (1) 15 to 20 per cent; (2) 10 per cent; (3) 10 per cent, and (4) 100 per cent. It is shown, however, that all four maximum increases are not simultaneously possible and that the increase estimated for the wider use of cracking processes implies a marked and apparently improbable decrease in the use of fuel oil. The paper shows also that the general use of kerosene distillates as fuel in internal-combustion engines would not increase the total supply by more than 55 per cent.

The general conclusion is that the wider use of cracking processes is the one important possibility of increase, and that this is subject to considerable advances in the art of cracking and to a notable decrease in the use of fuel oil.

As one of a series of papers discussing future prospects for a supply of internal-combustion engine fuel, the Bureau of Mines has been asked to present information relative to the efficiency of present-day petroleum refinery practice. The Bureau is sufficiently acquainted with this subject to realize the inadequacy of the data upon which discussion must be based. The figures given are actually nothing more pretentious than a series of

[1]Published by permission of the Director of the Bureau of Mines.
[2]Petroleum chemist, Bureau of Mines Experiment Station, Pittsburgh, Pa.

Digitized by Google

rough estimates, and any constructive criticism that may be offered regarding them will be welcomed.

Possibilities of Advance in Refinery Practice

The several most important ways in which the petroleum refining industry can increase the output of gasoline from a given quantity of crude oil may be listed as follows[2]:

(1) Universal adoption of a high "end-point" or upper volatility limit for gasoline
(2) General use of more efficient distillation methods and equipment
(3) Recovery of gasoline now lost in refinery operations
(4) Wider use of cracking processes

There are considerable differences in the grades of gasoline marketed throughout the country by different refineries and sometimes at different times by the same refinery. A notable point of variation is the upper volatility limit, or end-point. In the days when gasoline was simply a by-product of the refining industry, the end-point figure was approximately 150 deg. cent. (302 deg. fahr.). This type of gasoline is now practically extinct, and the so-called "high-test" engine fuel now marketed in relatively small quantities has an end-point of approximately 175 deg. cent. (347 deg. fahr.). The usual grades of gasoline are represented by end-point figures between the limits of 200 deg. cent. (392 deg. fahr.) and 230 deg. cent. (446 deg. fahr.).

The fact that gasoline of as high end-point as 230 deg. cent. (446 deg. fahr.) is being used in tremendous quantity and with satisfactory results renders it desirable to consider the possible increase in engine fuel supply if this upper volatility limit were universally maintained. The Bureau cannot go on record at present as either advocating or opposing such a standard, but is simply discussing what might be accomplished in the way of increased gasoline production if it were adopted. The present estimate, based on miscellaneous data at hand, is that from 15 to 20 per cent more gasoline would be available if a universal end-point equivalent to that of

[2]One other possibility might be mentioned; the refining of crude petroleum now marketed as fuel oil without removing its naphtha content. The Bureau has not, however, succeeded in uncovering statistical evidence indicating that developments in this line could augment production by a maximum of more than 3 to 5 per cent of the quantity of gasoline now refined.

Digitized by Google

the "heaviest" grade at present marketed in quantity should be maintained.[4]

The possibility of such a standard is, incidentally, dependent upon either a considerably increased production of casinghead gasoline or the development of engines that can utilize liquid fuel having smaller properties of volatile constituents than the types now marketed. The high end-point gasoline now marketed is almost invariably of the blended casinghead type.

The distillation methods employed by petroleum refineries do not operate with the same degree of efficiency that is attained in some other industries. Certain percentages of hydrocarbons boiling below the accepted upper temperature limit for gasoline are always present in kerosene or fuel oil. This does not necessarily discredit the technical ability of refiners, many of whom are maintaining as high a degree of distillation efficiency as is profitable under present commercial conditions. There is no doubt, however, as to the possibility of augmenting the gasoline supply through an increase in the average distillation efficiency of refineries, and it is important to estimate the order of magnitude of the probable gain.

Here again exact data are lacking, and reliance has been placed on miscellaneous indirect evidence. The probability seems to be that efficiency in gasoline recovery varies in different refineries between the limits of 75 and 95 per cent. The latter figure is probably about the maximum that can be economically attained, and the average is undoubtedly not lower than half way between the limits. It is, therefore, improbable that the Nation's supply of gasoline will be increased more than about 10 per cent through advances in the technique of large scale petroleum distillation.

Recovery of Gasoline Lost at Present

Bureau of Mines refinery statistics for 1917 and for the first seven months of 1918 show that an average of

[4]In this connection it is interesting to note the probable increase that would result if the end-point universally adopted were sufficiently high to include the fractions of petroleum now marketed as kerosene. Bureau of Mines refinery statistics for the calendar year 1917 show that about 20 per cent of the crude petroleum refined was marketed as gasoline and about 11 per cent as kerosene. If, therefore, the end-point selected were high enough to include both of these fractions, instead of stopping with a figure representative of the "heavy" engine gasolines of today, the resulting increase in supply would be 55 per cent, instead of 15 to 20 per cent. Wherefore, it appears that even the long-sought kerosene consuming engine is not going to keep the automotive industry on "easy street" for many years.

Digitized by Google

about 4 per cent of the crude oil treated was lost in the course of refinery operations.[5] Part of this loss was, of course, inevitable, but part represented gasoline that escaped with refinery gases. Recovery of this gasoline could have been effected by the use of methods and equipment similar to those employed for the production of casinghead gasoline. Such processes are already successfully operating, and there is no reason to doubt that the extraction of gasoline from refinery gases will eventually become a general practice.

Assuming that half of refinery losses are preventable in this way, it appears that gasoline amounting to about 2 per cent of the crude oil refined and about 10 per cent of the gasoline produced could be added to the supply of motor fuel.

The wider use of cracking processes is without doubt the most promising means by which refiners can increase their output of gasoline from a given amount of crude petroleum.

In a paper presented before this Society about a year ago,[6] I ventured to state an opinion to the effect that, if cracking processes were employed to the full extent of their applicability, the total production of gasoline from the quantity of crude oil now produced might be doubled. This statement is one that indicates considerable optimism for the future of the cracking art, and the Bureau has been agreeably surprised at its failure to arouse controversy. To prevent any future misinterpretation, it is perhaps best to make clear the fact that this statement implies a possibility, the commercial feasibility of which is yet to be demonstrated.

The future of cracking processes may be affected by the development of unfavorable conditions of various sorts. Two in particular deserve mention in the present connection.

Up to date, the development of the art of cracking has been far from complete, in spite of the considerable attention that has been given to this line of technical operation. Only one process, that of Burton, is today a real commercial factor in the production of motor fuel, and this is representative of a type that seems to in-

---

[5]Senate Document No. 280, Sixty-fifth Congress, second session. Letter from the Director of the Bureau of Mines, entitled "Production of Crude Oil," Sept. 24, 1918.

[6]"Fuel for Automotive Apparatus," by E. W. Dean, JOURNAL OF THE SOCIETY OF AUTOMOTIVE ENGINEERS, vol. 2, No. 1 (January, 1918), page 47.

Digitized by Google

volve certain inherent limitations in applicability. If the cracking reaction is to be applied to the extent necessary for a doubled gasoline production, other types of processes must be put into successful commercial operation, or the present apparent limitations of the class in which the Burton process belongs must be obviated. The Bureau of Mines is optimistic regarding the future commercial success of several other processes, but believes it is only fair to state that such success is not known to have been attained, as yet, in any large measure.

A second development that may restrict cracking operations is the existence of an unfavorable ratio between the market prices of gasoline and fuel oil. The production of cracked gasoline necessitates the consumption of fuel oil, and, if the demand for the latter commodity exceeds the supply, its price is bound to rise and the margin of profit on cracking processes will be wiped out. It is an open question whether the consumption of fuel oil can ever be reduced sufficiently to permit doubling the production of gasoline by the use of cracking processes. The Bureau of Mines cannot venture any prediction in this line, except that the price of gasoline is likely to exceed the present level before cracking processes will be employed to the extent indicated.

Summary

The estimates included in the present series apparently indicate that the refiner may be able to augment his production of gasoline from a given amount of crude petroleum by from 35 to 40 per cent, exclusive of the gains possible through wider application of the cracking reaction. Some of the possibilities, however, overlap each other, and a more probable summation estimate is 25 to 30 per cent. The Bureau believes that, if commercial developments are favorable, the wider use of cracking processes may permit of further increases up to a possible additional 100 per cent. No prediction, however, is ventured as to what part of this figure will actually be attained.

It may be mentioned, also, that the development of engines capable of utilizing the combined gasoline and kerosene fractions of crude petroleum would not be likely to alter the limit of maximum increase, but would materially hasten the day when it would be attained, and would, in considerable degree, help to keep the price of liquid fuel from ascending to painfully high altitudes.

Digitized by Google

The present paper may have produced the impression that the Bureau of Mines is not enthusiastic over the advantages to be gained by the development of a kerosene-consuming internal-combustion engine. Such is not the case, but it must be emphasized that this is not the only line along which the automotive industry must work.

In preparing this paper, the author has made very extensive use of statistical information collected by H. F. Mason of the Bureau of Mines. The evidence upon which estimates are based has been reviewed with H. H. Hill, J. P. Smootz and E. E. Lyder of the chemical staff of the Bureau of Mines, Petroleum Division, and the figures given have been agreed upon as most probable.

THE DISCUSSION

HUGO C. GIBSON:—The paramount thought expressed by all authorities on this vexed subject is that we cannot have the easily vaporized engine fuel; that we must be content with the higher boiling point, and that it is "up to" the engine. I agree with this and believe that the solution which will avoid too sudden a change and partial disorganization of the automobile business is to educate the public to modify their demand for a vehicle that will do sleight-of-hand tricks in getting under way at the touch of a button and will require no attention under extreme atmospheric changes of temperature; to educate them to be as economical of their fuel as the public of other countries not so blessed as this in the ownership of the actual source of supply of their fuel; to make them realize that specific devices must be employed to overcome the difficult problem now facing them, and that the application of these devices to automobiles will necessarily increase the prime cost of the vehicle, but that it will reduce the high future cost of pleasure motoring and of food and merchandise produced or transported by motor vehicles; to educate them to realize that they are today discarding, wasting, a large proportion of these natural resources and that with the cooperation of the automotive manufacturer the wastage will be saved.

At present the public blames the refiner for the poor gasoline, whereas it is not the fault of the refinery or its product that we break up our engines and deplete our pocketbooks any more than it is the fault of the kitchen that we break a tooth and damage our digestion on the pearl concealed within the oyster. The pearl is there by

Digitized by Google

beneficence of nature and force of circumstances. It is our fault if we do not recognize the pearl and place it in an appropriate setting so that it may become of maximum value. The advantages of economy in the refinery will accrue, but these economies are, while essential, of somewhat minor importance in comparison with the wanton waste of the mickle per engine which makes a muckle for the country.

I had the pleasure of conducting a test recently in which twenty automobiles of various makes each traveled 1000 miles, traversing five States, including New York and the District of Columbia. Some of them used gasoline and some kerosene with a small quantity of gasoline separately used for the purpose of starting and warming up. The consumption was markedly decreased in the case of all the cars which used special applications of heat in the vaporization of fuel. An increase of mileage per gallon of fuel of 50 per cent was general, including those using kerosene. The engines of most of the kerosene users showed little or no carbon and their crankcase oil condition was generally excellent. They required but little more attention than the gasoline cars. The educative value of such publicly conducted tests is inestimable. I apprehend that coordinated effort on the part of the producer, the refiner and the automotive manufacturer along such lines will discover the pearl to the user. That done, the way to save the wastage from the oil well to the user will be easier. I ask that a committee be appointed to coordinate the powerful interests on the problem, and to formulate the mechanism necessary for attainment of the end in view.

DR. JOSEPH E. POGUE:—Dr. Dean clearly points out the pivotal bearing of cracking upon the engine fuel supply. As matters now stand, the automotive future is dependent upon the competency of cracking to a degree difficult to exaggerate, and the importance and potentiality of this principle should not be underestimated. Cracking, if unaffected by retarding economic factors, can apparently expand over a course of years so as to lead to a doubling of the supply of gasoline as compared with the quantity obtainable without its aid. Also there are reasons to believe, although substantiating figures cannot be adduced at the present moment, that the operating cost of the process in widest use is fairly slight. But in placing reliance upon cracking, the automotive industry should not fail to consider the retarding factors that Dr. Dean

Digitized by Google

mentions, as well as others, including patent limitations, the time required for the acceptance and installation of cracking processes by refineries not already so equipped, the difficulties in respect to favorable yields with asphaltic crudes and possible restrictions in expansion for purposes of financial advantage. There are few subjects that stand more in need of adequate economic study than cracking. The matter can scarcely be properly valued with the data in hand. In the imperfect light that now falls upon this matter, however, it appears that the principle offers a growing increment to the gasoline supply, but one that scarcely can be sustained in sufficient magnitude unless the automotive apparatus, at least, permits the supply of gasoline at the same time to expand in such direction as to include successive strata of the kerosene cut, the area least affected by cracking possibilities.

So much is discernible ahead with some measure of clearness.

Digitized by Google

AN INTERPRETATION OF THE ENGINE-FUEL SITUATION

By Dr Joseph E Pogue[1]

THE automotive industry is developing without due regard to the fuel situation. This situation is an integral part of the automotive field and should not be left out of account. Owing to the pressure of automotive demand, the supply of engine fuel is changing in character and price, with danger of precipitant alterations; there arises in consequence a fuel problem which cannot be adequately solved without the active participation of the automotive industry.

An analysis of the problem is as follows: (*a*) The domestic production of crude petroleum is nearing its maximum; (*b*) the natural gasoline content of this supply is decreasing; (*c*) Mexico offers no permanent relief competent to solve the issue; (*d*) substitute fuels do not alter the situation; (*e*) the supply of engine fuel can be maintained only through an extraordinary dependence upon cracking or through adaptations in the engine; (*f*) cracking cannot meet the issue at a favorable price, and (*g*) the burden, therefore, falls upon the automotive engine, which must consequently so adapt itself as to gain higher thermal efficiency, and to use less specialized, less volatile, fuel.

The automotive industry should, as an emergency measure, take steps at once to shape its development in the direction of increased fuel economy and less specialized requirements as to fuel, establishing for this purpose centralized machinery to study the problem in full detail; to keep the industry informed of every development in the situation; to co-ordinate research and design in the competing units of the industry; and to conduct basic lines of research not now adequately encompassed by individual agencies.

The principal factors in the engine-fuel situation are the demand for liquid fuel and the adaptability of the internal-combustion engine on the one hand and the supply of crude petroleum, the gasoline-producing capacity of this material, and the substitute fuels in sight, on the other. Out of the interplay of these factors

---

[1]Assisting director in technical matters, bureau of oil conservation, oil division, United States Fuel Administration, Washington.

Digitized by Google

will come developments, focussed in the price of engine fuel, that will determine the future of the automotive industry.[2]

The Demand for Engine Fuel

The demand for engine fuel has been increasing over the past few years at an imposing rate. The nature of this expansion is shown graphically in Fig. 1. The construction program of automotive manufacturers, moreover, affords no prospect of let-up in the pressure of fuel requirement; on the contrary, the injection into the situation of a notable development in the capacity for truck production introduces an element that bids fair to overshadow even the tremendous automobile demand, while the item of tractor manufacture looms ahead with a fuel significance scarcely second in importance. If these matters be projected into the future unabated, it is evident that the supply of engine fuel will need to be doubled every few years. The automotive industry is young and vigorous, and its continued expansion will place an unexampled burden upon the engine-fuel resources of the country.

Adaptability of Engine Type

The automotive engine has developed and become standardized in its main features on the basis of cheap and volatile gasoline. Its improvement has for the most part followed the direction of convenience and performance, with secondary consideration to fuel economy. This trend has been sustained to the present time by the existence of a highly stimulated oil production, providing gasoline capacity in excess of gasoline demand. So long as this condition obtained, there was no need for the automotive industry to concern itself with considerations of fuel supply, but now, with the gasoline capacity of the country beginning to give indications of strain, while the gasoline demand is just fairly getting launched, the question arises whether the exigencies of the future will allow the engine type continued freedom of development in

[2]The validity of the conclusions presented in this paper depends upon the correctness of the writer's diagnosis in respect to four basic points: The domestic supply of crude petroleum, the significance of Mexican petroleum, the significance of cracking, and the adaptability of the automotive apparatus. An independent check upon these points, which will serve to substantiate, modify or controvert the present argument, will be afforded by the other papers presented at the Fuel Session of the Annual Meeting of the Society, as well as by a study of the references given at the end of the paper.

Digitized by Google

luxury directions, or will force adaptations to meet the exactions of the fuel situation.

Automotive apparatus is mechanically responsive to changing requirements, but its adaptation to new conditions is retarded by the time required to perfect mechanical developments and the counter advantage to be

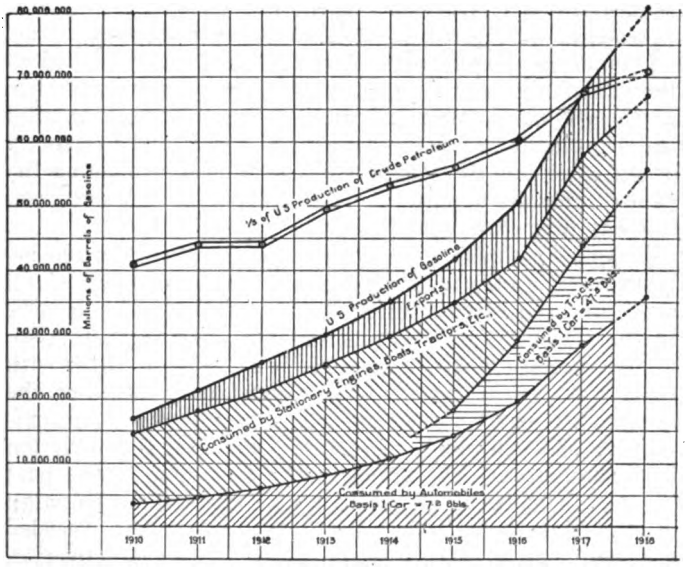


FIG. 1—THE GASOLINE SITUATION

This composite chart is drawn from data as follows: Crude production from U. S. Geological Survey; gasoline production from U. S. Fuel Administration and U. S. Bureau of Mines; automobile and truck consumption based on registration compiled by National Automobile Chamber of Commerce, and consumption factors worked out by War Industries Board (see manuscript report by M. J. Gillen on Regulation of Uses of Motor Cars, Gasoline, Rubber Tires and Rubber, Nov. 4, 1918). This chart is not exact in final detail, but is an interpretation of data approximately correct.

gained from quantity production and standardization, with their antagonism to change. So far-reaching and insistent, indeed, are the claims in favor of holding fast to established standards, that departures can be made only at great cost and in response to powerful reasons. Anticipatory action becomes peculiarly difficult in the face of these circumstances. Recognizing the strength of the factor opposing changes in engine type and seeking to force the fuel supply into channels fitting the established standards, we may examine the fuel supply with

Digitized by Google

a view to determining if present engine standards can be advantageously maintained, and, if not, along what lines changes are likely to be made.

Supply of Engine Fuel

The engine fuel in dominant use in the United States is gasoline, a mixture of volatile liquids won from crude petroleum by a process of distillation.[3] Kerosene, fuel oil, lubricants, and various by-products are produced at the same time, and bear an intimate relation to gasoline, as to both production and price. The relative output of these products in 1917 is shown in Fig. 2. The quantity of gasoline that the country is capable of producing depends upon the supply of crude petroleum and the gasoline capacity of this material.

Supply of Crude Petroleum The supply of crude petroleum for years to come depends upon the unmined reserve and the rate at which it may be won. The reserve in the United States was inventoried by the U. S. Geological Survey in 1908, in 1915, and again in 1918, with results shown in Fig. 3. The significant aspects of the results are two: The small size of the reserve, approximating 7,000,000,000 bbl. in 1918 (our annual production is over one-third billion), and the fact that in the past 10 yr., in spite of an exceedingly aggressive campaign of oil exploration, the decrease in the reserve has exceeded the addition to the reserve through new discoveries. Those, therefore, who count upon new discoveries to materially affect the basic situation overlook the fact that already for ten years discoveries have been failing to do so.

At the same time the production of crude petroleum has been steadily mounting to its present enormous figure. This growth in output, shown in Fig. 3, has been sustained, not primarily by the discovery of new oil fields, but largely by the cumulative tapping of an increasing number of rich spots in inventoried territory. There is obviously a limit to an output supported by such a train of circumstances; there are strong engineering and economic reasons for believing that the output of crude petroleum in the United States is nearing its maximum and that the country will soon pass into a period of slowing and more costly production.

[3] A small proportion of the supply is extracted from natural gas, but this does not largely affect the general situation.

Digitized by Google

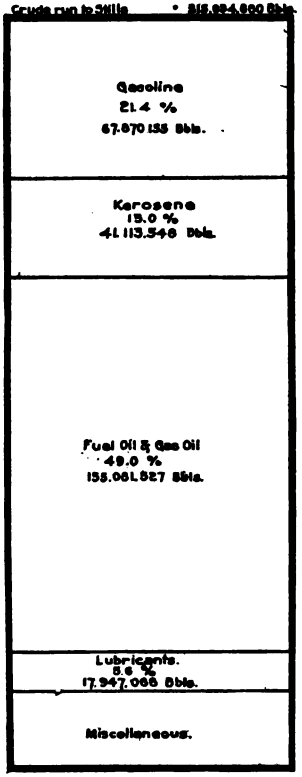


FIG. 2—GASOLINE AND ITS JOINT-PRODUCTS
Data from U. S. Fuel Administration

Gasoline Factor The output of gasoline approximates[4] the supply of crude petroleum multiplied by its commercial gasoline factor,[5] which at the present time is about 20 per cent. This factor, like the supply of crude petroleum, is itself a variable figure depending upon the proportion of the crude supply subjected to refining, the natural gasoline content of this quantity, and the extent to which means are used for forcing the gasoline yield above the natural gasoline content. Obviously, as

[4]Because of the subordinate item of gasoline produced from natural gas, the relation is not an exact equality.

[5]The commercial gasoline factor is here used to represent the percentage of gasoline obtained from the crude consumed; the natural gasoline factor is the percentage of gasoline contained in the crude consumed. The first has increased until it has overtaken the second. (See Fig. 1) The terms are used in a general sense.

Digitized by Google

long as the natural gasoline is not fully extracted from the available crude, there is scant economic room for the development of round-about, ie., more intricate, more costly means for producing gasoline. This was the situation that prevailed in the United States until recently; this is why natural-gas gasoline, cracked gasoline, and low-volatile gasoline are all recent commercial developments.

The proportion of the crude supply subjected to refining in respect to gasoline has been steadily increasing until the quantity so employed now approximates 95 per cent of the total.[6] Thus, practically the whole output has now come to be requisitioned for gasoline production. This is to say that the readiest means for increasing the supply of gasoline, i.e., refining a progressively larger percentage of the crude produced, has been virtually forced to its limit; the "gasoline slack" within the crude production has been taken up. Hence, the most potent circumstance that has so far enabled the demand for gasoline to increase without a concomitant increase in price, is no longer in existence (see Fig. 1). Further expansion in gasoline output will lie through more difficult avenues than that of merely increasing refinery capacity.

While dependent primarily upon the quantity of crude refined, the output of gasoline is at the same time a function of the average composition of the various crudes that go to make up the total supply. Since crude petroleum varies in its natural-gasoline content[7] from about 2½ per cent in the case of heavy, asphaltic oils to 25 per cent or more for light, paraffine oils, it is evident that the gasoline supply will be strongly influenced according to the dominance of the one or other type of oil. As the high-gasoline crudes were the first to be exploited in this country, the unmined supply of petroleum has been selectively reduced in gasoline capacity,[8] so that the crude production of the future will show a lower natural-gasoline factor than the crude supply of the past. While this matter cannot be expressed quantitatively, in very rough

[6]A much smaller proportion, of course, is subjected to complete refining with the production of the whole range of petroleum products.

[7]This term is used in a practical, rather than a strictly scientific, sense.

[8]The gasoline content of crude oil has been known to decrease even during the life of a given pool, which is a tendency in the same direction as that occasioned by selective extraction in respect to separate pools and fields.

Digitized by Google

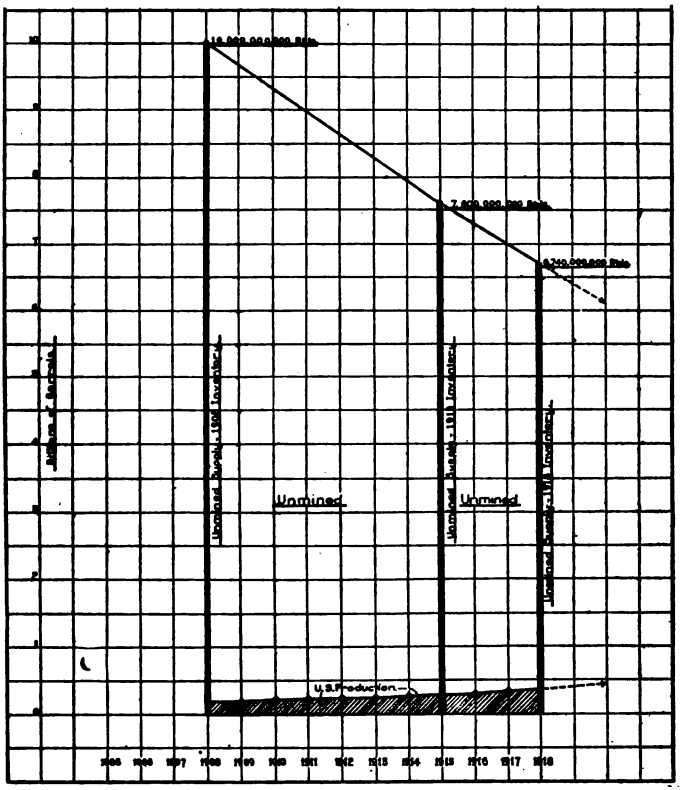


FIG. 3—THE DOMESTIC CRUDE PETROLEUM SITUATION
Data from U. S. Geological Survey

terms it may be noted that the high-gasoline crudes are about half exhausted, while the low-gasoline crudes, originally of about equal magnitude, are only about a third used up. In other words, the country's gasoline capacity is being drawn upon more rapidly, and hence exhausted more quickly, than is indicated by the condition of the crude supply viewed alone. This tendency was of no immediate consequence so long as it could be compensated by merely refining a greater proportion of the output of crude; but now, since practically all of the domestic crude is used for gasoline extraction, a decline in gasoline content can be offset only by shoving crude production to a higher figure than would otherwise be necessary, or else through a still greater use of means for wresting an unnatural percentage of gasoline from the crude obtainable.

Digitized by Google

The means for producing more gasoline than may be obtained by subjecting the total supply of crude to straight refining are: (*a*) increasing refinery efficiency, (*b*) blending high-volatile natural-gas gasoline with low-volatile refinery gasoline, (*c*) increasing the use of cracking in refinery practice, and (*d*) lowering the volatility of gasoline. All four means are increasing in use. For the sake of brevity, the first two may be passed over with the comment that, while important, they have quantitative limitations which prevent them from broadly affecting the situation. This is not true of the second two, the limitations of which are of a different order.

Cracking is a process attachable to straight refining, by means of which low-priced distillates such as kerosene and fuel oil are rerun under more rigorous conditions and partly converted into gasoline. Obviously, cracked gasoline costs more to produce than natural gasoline, because of a greater consumption of capital, labor, material and fuel, and is commercially possible only after gasoline requirements have approached the quantity producible by straight refining, and as long as there is a certain difference in market value between the raw materials used and the product turned out. The first condition has recently been attained, and there is already economic room for cracking; the second condition, if the prices of kerosene and fuel oil rise, can be maintained only by a proportionate increase in the price of gasoline. The prospective growth in the use of the Diesel engine, especially for marine service, with its high fuel economy in the consumption of heavy petroleum distillates, may be expected to lessen the advantage that at the present moment accrues to cracking. Although the price of fuel oil is limited by the price of coal, the advantages of oil over coal for marine service are so marked that fuel oil can probably rise to $5 to $10 per bbl. before reaching its limit. Another no less potent factor bearing unfavorably upon the aid that the automotive industry may expect from cracking, is the circumstance that the cost of cracking becomes greater as the percentage of gasoline demanded of a given quantity of raw material increases. This means, so to speak, that a little cracking may spread rather rapidly to all the crude refined, but much cracking will involve a step-up to a higher level of costs. In addition, the retarding influence that private control of patents will exert upon a widespread use of cracking processes should not be left out of account. Op-

Digitized by Google

posed to these unfavorable economic aspects of cracking, which offer relief only upon a basis of higher prices, is the matter of advance in cracking technology toward increased efficiency and lowered costs. Progress of this kind is undoubtedly in store, but advances under this head must work within the broad economic restrictions laid down above, and can scarcely be counted on to more than temper the price advances competent to maintain the requisite increase in cracking output. On the whole, then, there are reasons to believe that cracking, while of great importance at present, will under expanding use develop toxic properties, so to speak, which will limit its field of operations, if not ultimately remove it largely from the scene of action.

The fourth means for enlarging the output of gasoline independently of the production of crude is through lowering the volatility of the product. The less specialized the engine fuel in respect to volatility, the more can be produced from a given quantity of crude by the processes of refining in general use (see Fig. 2). By a change in character, the supply of "gasoline" can be enlarged, slowly or rapidly at will, without material refinery changes, until it is two to three times the present figure, even with no increase in the supply of crude. Since the materials requisitioned in such a change are the basis of kerosene and fuel oil, which can be replaced almost entirely by coal and its products, the transition may be made without a basic disturbance of the country's economic fabric and without setting up counter forces tending to turn back the tide, as would be the case in an over-dependence upon cracking. The practical limit to this enlargement, however, is set by what the standardized automotive engine will accept in the way of fuel; which is to say that this avenue of advance is wholly in the hands of the automotive industry. The progress of gasoline in this direction has already gone about as far as practicable under existing standards of mechanical equipment; if the fuel current finds an unbreakable dam at this point, the whole pressure of advance will be thrown back into the channels already reviewed. Inasmuch, however, as the past few years have seen the volatility of gasoline steadily decreasing, in spite of laws and the desires of the automotive industry and the public to the contrary, while engine design has already been forced to respond to this circumstance with superficial adaptations, it is apparent that the channels of crude

Digitized by Google

production, cracking, etc., have already demonstrated their incapacity unaided to accommodate the rising flood of gasoline demand. If these mainstays of the automotive industry are failing to meet the issue now, it is hazardous to count upon complete relief in this quarter when the pressure focussing there is rapidly increasing.

Bearing of Mexico Upon the Situation

We have seen, so far as the petroleum situation in the United States is concerned, that an increasing supply of gasoline of present grade can be maintained into the future only through a growing use of cracking processes, involving material increases in the cost of production. But there are large oil deposits in Mexico which are believed by many to be capable of sustaining a North American supply of crude sufficient for all demands, even in the face of a slowing domestic output. What bearing does this factor have upon the engine fuel situation?

The oil-producing capacity of Mexico is certainly great, but the size of the underground reserve that will have to sustain production is largely an unknown quantity. The geological occurrence of Mexican petroleum is widely different from that of oil in the United States, and is of such a nature that the unmined supply cannot be readily inventoried. The output of Mexico to date has come largely from two wells of prodigious capacity which have been held in check, but one of these wells is recently reported to have gone to salt water. There are, in addition, political difficulties in the way of the exploitation of Mexican petroleum, while the output will have to go in part to Great Britain, whose subjects hold extensive interests in the Mexican fields, and to other foreign countries. Mexican deposits are also involved in a large and growing fuel-oil demand in respect to the merchant marines and navies of Great Britain and the United States, which alone will tend to exhaust them rapidly.

Of even greater significance to the engine-fuel situation, however, than the quantity of crude that Mexico may be expected to contribute to the domestic supply, is the natural gasoline factor of this contribution. Unfortunately the natural gasoline content of Mexican petroleum is low, so that the more the domestic supply of crude is supplemented by imports from Mexico, the more the natural-gasoline factor of the entire crude supply is reduced, the more must cracking methods be called upon to sustain the production of gasoline. Thus, not only is

Digitized by Google

the future of Mexican production a subject upon which adequate information is wanting, but, with the most optimistic assumption in that respect, the character of the supply is such as to be capable of sustaining an output of gasoline only upon a higher level of production costs[9] than now prevails. Thus Mexico, instead of offering a solution to the engine-fuel problem, promises only to accentuate the issue; especially as the sudden leap in production that is impending from this source will lend a strong color of assurance to the situation.

The statements thus far made in respect to Mexico may, without substantial qualification, be extended to include the oil fields of Central America as well, which will probably turn out to be heavy producers. As to South America, rather extensive explorations in most of the countries have failed to locate oil deposits of sufficient magnitude to bear materially upon the situation in the United States.

Significance of Substitute Engine Fuels

The petroleum industry is so firmly established and produces such a range of products other than gasoline, that no engine fuel of non-petroleum origin need be counted on as capable of displacing gasoline.[10] Substitute fuels are to be regarded as supplementary resources, capable of affecting the situation broadly only as petroleum relinquishes the field through exhaustion.

There are three substitute engine fuels in sight—benzol, alcohol, and shale-oil distillate. Benzol is now ready to compete with gasoline in a small way; alcohol and shale-oil distillate will be ready to compete only on a higher level of prices. As to resource capacity, benzol is a by-product of coal, and the quantity produced is dependent upon the coal subjected to by-product recovery; benzol will be manufactured in constantly increasing quantity, but the total supply can never fill more than a small part of the engine-fuel requirement. Alcohol and shale-oil distillate, on the contrary, are main products made from raw materials of almost unlimited availa-

[9]This may not be strictly true of gasoline produced in Mexico itself as a by-product of fuel oil for a period following the establishment of large "topping plants" and in event of sustained production in that country of crudes containing appreciable quantities of gasoline; but imported gasoline can scarcely be counted on in quantities large enough, or sufficiently soon, to materially affect the situation in the United States.

[10]Gasoline can be sold cheaper than any competitor, because of the possibility of shifting part of its cost of production to the joint products.

Digitized by Google

bility; they may be produced to fill any need, however great, willing to pay the price. Whether shale-oil distillate or alcohol will eventually become the more important engine fuel cannot wholly be foreseen; but since shale oil is similar to crude petroleum and can be made to yield an analogous range of products, a shale-oil industry is certain to supplement and eventually to succeed the petroleum industry, and hence shale-oil distillate is bound to become eventually a prominent motor fuel.[11] Alcohol, on the other hand, is not so tied up with joint products, and its career as an engine fuel will be determined almost entirely by relative economy and its acceptability to engines evolving on the basis of oil fuel. If the engine type broadens so as to fit the petroleum resource, it will at the same time be prepared to receive the aid that benzol, shale-oil and alcohol may be called upon to render.

On the whole, then, there is nothing in the substitute engine-fuel situation that would dictate to the automotive industry a policy differing from that determinable upon the basis of the petroleum issue. The substitute fuels remove any physical limit as to the quantity of engine fuel that may be produced; they offer greater assistance to the situation if present standards are less rigorously adhered to and automotive apparatus becomes adapted to a less volatile fuel than gasoline; they set the bounds to which the price of engine fuel of petroleum origin can advance—a very rough approximation of this figure being relatively 50 to 60c. per gal:—suggesting, therefore, to the automotive industry an increase in thermal efficiency competent to offset the advance in price which the substitute fuels will permit and the petroleum situation will occasion.

Coordination of the Industry and Fuel Supply

The foregoing analysis of the resources and technology underlying the prospective supply of engine fuel indicates that the continued growth of the automotive demand will soon force either an extraordinary dependence upon cracking, with concomitant increases in production costs, or else a change in the character of the fuel so as to include more and more of the material now going on the market in the form of kerosene and fuel oil. The

[11]It should be remembered, however, that many years must elapse before a shale-oil industry can become established and grow to significant proportions.

Digitized by Google

first adjustment is limited by the physical capacity of cracking, which is largely an unknown quantity, and the extent to which fuel costs can rise without involving curtailment in the growth of the automotive industry. The second solution is dependent upon the extent to which automotive apparatus may be adapted to consume a fuel less volatile than gasoline. Running through each solution, and serving to contribute to each, is the extent to which the thermal efficiency, or fuel economy, of the automotive apparatus may be increased. The more rigorously the present standards of low economy and specialized requirements are adhered to by the automotive industry, the greater the weight that will fall upon cracking, the greater and more sudden the inevitable rise in fuel price and the graver the danger of an industrial reverse.

The fuel resources in sight indicate that a normal balance between supply and demand will eventually be reached, irrespective of the policy of the automotive industry, but the adjustment will result in a basis of price and character different from that now prevailing. The danger in the situation is not that of a permanent breakdown in fuel supply through exhaustion, but of a period of enforced readjustment to new conditions of fuel supply, which may come so suddenly as to catch the automotive industry unprepared and in consequence impose a serious handicap upon its prosperity, if it does not precipitate industrial disaster.

The situation is serious, indeed critical, not only because the period of readjustment is apparently almost upon us (see Fig. 1), but because there are many aspects of the situation that tend to hide the real issues and to lend a false sense of security to those filled with an excess of optimism. American economic experience affords no parallel to the present engine-fuel situation; as demand in the past has almost invariably conditioned supply in American economic practice, it is an easy assumption that this will continue to hold in unabated vigor. New discoveries of oil pools are constantly coming into prominence. While the outlook for oil production never before appeared brighter, one easily overlooks the fact that each new pool, in proportion to its magnitude, adds to the instability of the engine-fuel structure. At this very moment of writing, gasoline is piling up in storage and it is quite possible that before the winter is over the price will decline slightly. This may readily

Digitized by Google

be accepted as controverting the whole argument of the paper, if the circumstance is not recognized as an inevitable reaction to a coincidence of season and post-war industrial readjustment. Upon all this come widely heralded announcements of new fuels, with extravagant claims and secret formulas, boldly promising at one stroke an easy solution of one of the most complicated industrial problems this country faces today. There are indeed specious arguments for sustaining conclusions quite the reverse of those arrived at here. While one series of circumstances is operating cumulatively to render the engine-fuel situation more and more unstable, another set is serving to hide the real issue to the last.

There is scant hope, at this late date, that the automotive demand will be brought into stable adjustment with the engine-fuel supply with results wholly conducive to the prosperity of the automotive field, but such difficulties as lie in store may be tempered if the industry as a whole recognizes its responsibility in this matter and acts accordingly. The exigencies of the fuel situation now urge, but shortly will demand, that the automotive industry work toward greater fuel economy and at the same time adapt its mechanical equipment to handle a less specialized fuel than gasoline. The first can be accomplished in some degree through car design, but in the main must depend upon engine changes in favor of greater thermal efficiency. The second can be accomplished either through the development of equipment not dependent upon fuel of high volatility, so as to permit the supply of "gasoline" to expand easily, or else by inducing the engine-fuel supply to bifurcate into gasoline of the grade at present reserved for passenger cars, and heavier distillates to be drawn upon by trucks, tractors, etc., fitted with semi-Diesel or other type of engine suited to such fuel. Apart from the disadvantage of greater costs involved in the production and distribution of two specialized fuels in the place of a single product, and the practical difficulty of unloading the problem on the heavy-traction section of the automotive industry, the second expedient would in reality mean merely the turning over of the raw materials of cracking to a counter-demand and would leave the gasoline problem still in acute need of attention. So the economics of the situation, the dictates of resource limitations and human needs, point to an automotive engine evolved into a type fitted to gain not only higher efficiency from the fuel consumed but greater economy in

Digitized by Google

respect to the activities involved in the production and distribution of the fuel. The answer then is: Greater thermal efficiency in the engine and means for gasifying liquid fuel without requiring that it first be converted by a costly manufacturing process into a highly volatile product difficult to store and to transport.

Summary

(1) The automotive industry is working without due regard to the engine-fuel situation.

(2) This situation is an integral part of the automotive situation and should not be left out of account.

(3) Owing to the pressure of automotive demand, the supply of engine fuel is in course of change, both in respect to character and price, with danger of precipitant alterations; there arises in consequence a fuel problem which cannot be adequately solved without the active participation of the automotive industry.

(4) An analysis of the problem is as follows:

(a) The domestic production of crude petroleum is nearing its maximum

(b) The natural gasoline content of this supply is lessening

(c) Mexico offers no relief competent to solve the issue

(d) Substitute fuels need not enter into present consideration

(e) The supply of engine fuel can be maintained only through an extraordinary dependence upon cracking or through changes in engine type

(f) Cracking cannot meet the issue at a favorable price

(g) The burden, therefore, falls upon the automotive engine, which must consequently so adapt itself as to gain higher thermal efficiency, and to use less specialized (less volatile) fuel

(5) The automotive industry should therefore take steps at once, as an emergency measure, to shape its development in the direction of increased fuel economy and less specialized requirements as to fuel, establishing for this purpose centralized machinery for studying the problem in full detail; for keeping the industry informed of every development in the situation; for coordinating re-

Digitized by Google

search and design in the competing units of the industry, and for conducting basic lines of research not now adequately encompassed by individual agencies.

Selected References

Those wishing to pursue the subject of engine fuel in further detail are referred to the following publications:

Arnold, Ralph. "The Petroleum Resources of the United States," Economic Geology, vol. 10, 1915; reprinted in Smithsonian Report for 1916, page 273.

Day, David T. "The Petroleum Resources of the United States," Bulletin No. 394, U. S. Geological Survey, 1909, page 30.

Dean, E. W., "Fuel for Automotive Apparatus," The Journal of the Society of Automotive Engineers, vol. 2, 1918, page 47.

Federal Trade Commission. "Report on the Price of Gasoline in 1915," Washington, Government Printing Office, 1917.

Gilbert, C. G. and Pogue, J. E. "Petroleum; A Resource Interpretation," Bulletin No. 102, part 6, U. S. National Museum, 1918.

Interior Department. "Gasoline." Letter from the Secretary of the Interior transmitting certain information relative to the production, consumption and price of gasoline, Senate Document No. 310, Sixty-fourth Congress, first session, 1916.

Northrup, J. D. "Petroleum in 1916," part 2, "Mineral Resources of the United States," U. S. Geological Survey, 1918.

Requa, M. L. "Petroleum Resources of the United States," Senate Document No. 363, Sixty-fourth Congress, first session, 1916.

White, David. Introduction to "The Oil Resources of the Public Land States," by W. B. Emory, Bulletin No. 689A, U. S. Geological Survey (in press).

THE DISCUSSION

B. B. Bachman: In this paper the author has given a general analysis of the trend of the automotive industry in the increasing production of apparatus calling for volatile fuels and the probable limitations on the part of available resources to meet this demand. The complexity of this problem and the contradictory evidence which has been presented from time to time make it difficult for one not in intimate contact with the subject

Digitized by Google

to evaluate the arguments advanced and the conclusions arrived at.

However much the author's opinion may be contradicted by other authorities, he should receive due credit for having the courage of his convictions in calling attention to what he conceives to be a danger to the future of the automotive industry. On the other hand, it is unfortunate that general discussions and pessimistic personal opinions on this subject are frequently abstracted by the press as affording news of a sensational nature which is very often misinterpreted by the untechnical reader. As much may be said for the publicity given in the same mediums of the many supposedly infallible remedies which have been proposed. In both cases the result is only to becloud the main issue.

The internal-combustion engine in the form used in automotive apparatus is unquestionably open to criticism from the standpoint of the thermal efficiency obtained. Lack of economy in installation in passenger vehicles and to a lesser extent, perhaps, in heavier vehicles, can also be charged with some propriety to the demand for flexible performance which has been created in introducing the product to the public and in fostering the competition between various manufacturers. Nevertheless, however much we, as engineers, may recognize the defects of our product and the lines along which progress must be made, it is not wise to blind ourselves to the advances we have made and the standards of performance which have been created. From the standpoint of light weight, durability, flexibility, power output per pound of material, cost and adaptability to its purpose, the modern gasoline engine is a marvel of mechanical achievement.

Quoting from the paper, the author tells us "American economic experience affords no parallel to the present engine fuel situation." We may as aptly say that history affords no parallel for the condition with which the author confronts us of creating a new device to function in competition with a machine that is so satisfactory, for the present, at least. If the fuel were known, together with its characteristics and peculiarities which would insure a stable condition of future supply, it would be more nearly possible to predict what the solution of this problem will be. Should it be necessary to curtail any of the excellent features of the present engine as outlined briefly above, it would appear that only cooperative action between the, at present, competitive units of the industry

Digitized by Google

would afford a possible means of successful introduction. Of course, if any individual by a stroke of genius should develop an engine which in addition to the present features possessed the advantage of offering a successful solution to this problem, he would, to use a colloquialism, be "sitting on the world."

It seems unthinkable that progress once inaugurated and carried to such a high state of development should be halted. The author says: "The danger in the situation is not that of a permanent breakdown in fuel supply through exhaustion, but of a period of enforced readjustment to new conditions of fuel supply, which may come so suddenly as to catch the automotive industry unprepared and in consequence impose a serious handicap upon its prosperity, if it does not precipitate industrial disaster." It seems to me that the consequences of such a catastrophe would be infinitely more far-reaching. The portable self-contained prime mover developed in the modern internal-combustion engine has wound itself so intimately into all our activities that it requires no great stretch of the imagination to conceive that its withdrawal would menace the structure of economic and political organization upon which rests the security of our civilization.

Merely to say a thing is unthinkable or impossible does not dispose of the question, and this leads me to call to your attention the fifth point of the author's summary. While there may be a division of opinion on the degree to which the deductions reached in the paper are true, there does not seem to me to be any doubt as to the wisdom of following this bit of constructive advice. It only remains then to consider the machinery by which this research shall be carried out. The nature of the problem would seem to indicate that the Society would be the organization best suited to bear the burden of a large part of this work, and the Standards Committee the organization through which it could be successfully accomplished.

It is well to remark, however, that this problem presents some novel features not at present encountered in the Standards Committee activities. First in practically all of the present work the problems are in the line of coordinating and establishing practices and methods of construction which will simplify manufacture and bring about economies by the elimination of an excessive and unnecessary variation in form and dimension of materials and parts of apparatus. This work can well be accom-

Digitized by Google

plished by the cooperation of men who are primarily engaged in other activities and who devote only a relatively small proportion of their time to their committee work.

It is obvious that such a procedure would not suffice for the problem under consideration. The committee to handle this proposition, by reason of the necessity of investigating a large amount of data and interpreting it, should include men competent by training and experience in the technique of the production and use of oil fuels, so that the results of their work would bear the stamp of authority. To do this properly and promptly will require more than the ordinary amount of committee work, and it accordingly becomes a problem as to how to secure the services of men of the caliber required. In addition to this, to complete the work it will be necessary to investigate substitute fuels, methods of fuel production, apparatus for using these fuels, and new methods of engine construction which, if followed by a verdict as to their value, will constitute a radical departure from our present practices and policies.

HUGO C. GIBSON:—Dr. Pogue carves the meat of the subject very neatly in the section of his paper entitled "Adaptability of Engine Type." It is only regrettable that he does not go further and tell us just how to accomplish the necessary end.

The controlling factors of carburetion are getting the heat in and getting it out for power and economy. Just so long as we could get gas in, because of a highly volatile liquid, the gas of which did not readily condense when cooled, there was no difficulty in following the law that the more gas and air we put in the more power we got out. The number of British thermal units generated was higher, the temperature in the cylinder was higher and the equation

$$E = \frac{H - Hl}{H}$$

was high. Today the endeavor is to put the mixture in as cool as possible because a cool mixture means a small engine for the power developed and a small engine means high load weight to vehicle weight ratio, incidentally meaning a high profit to turnover ratio to the manufacturer.

But the factor of greatest importance today is that our gasoline is not what it was and will not stay put as a gas at the temperatures at which we would like to intro-

Digitized by Google

duce it into the cylinder. It must be hotter or it will not vaporize or will condense. Fuel in the cylinder which is not in the form of vapor will break down and deposit heavy oils and carbon. The fuel value is lost to the extent of the heat units contained in the deposited material; so we lose the extra power we expected to get from the use of a cool mixture.

Since we cannot put the desired number of usable heat units when hot into the cylinder of small capacity we must, to obtain the desired amount of power, use cylinders of larger capacity or higher engine speeds.

Higher engine speeds mean reduced volumetric efficiency which must be made up by having the ingress and egress of gases easier. Ingress is assisted materially by increase of port area in sleeve-valve engines and multiplication of valves in poppet engines. Egress thus far appears to be treated in the same manner, ignoring interaction overlapping of exhaust-valve timing, a detail of the utmost importance, recognized and cared for by makers of six-cylinder engines but neglected in the case of four-cylinder units. It is a fact that four-cylinder and all engines are immensely improved by complete exhaustion, though arguments are advanced that the heat of trapped exhaust gases aids vaporization. It might, if the time element were greater; if the unvaporized fuel in the cylinder were exposed to heat for a longer time.

I would urge the thought that time is the essence of the conversion of modern, and more so of future, engine fuel into gas, and conclude by enunciating the cardinal factors controlling the effective use of the petroleum automotive fuels.

The fuel in mixture must be treated gradually by stages.

After vaporization the low limit temperature of the mixture should be maintained.

The passages to and from the engine must be large enough throughout to provide high volumetric efficiency.

The cylinder must be larger or the speed higher than formerly.

The exhausting function must be highly effective. Better mufflers must be used.

Cylinders, after complete exhaustion, must not be refuges for vagrant polluting gases from other cylinders.

Thus we will satisfactorily utilize the fuels that we can have.

DR. POGUE:—No intent is had to disparage the in-

Digitized by Google

ternal-combustion engine. The attainments on this score are, indeed, one of the notable achievements of the present century. The point may be fairly made, however, that the internal-combustion engine has not developed rapidly in respect to thermal efficiency for the simple reason that an abundant fuel supply is not conducive to such a development. If fuel stress develops, or may be anticipated, then the engine will duly respond to the new conditions. Up to the present, the engine has conditioned the fuel; it is an open question whether the fuel may not soon have an influence upon the engine. It is here that study and planning ahead are needed to coordinate engines and fuel, which are already beginning to work somewhat at cross purposes.

M. BECK:—What does the shale-oil industry look like?

DR. POGUE:—I should have mentioned the shale-oil industry, because, without question, it will be the successor to the petroleum industry. So far as the automotive industry is concerned, it can forget the shale-oil industry, as the coming in of shale oil, when the time arrives, does not materially affect the issue, since it is chemically and physically analogous to petroleum. The automotive industry will not know when the shale-oil industry comes in. It will wedge in with petroleum, as petroleum falls off; so it seems to me that shale oil in the offing does not affect the problem as it presents itself to you at the present moment. The matter of alcohol, which is a second substitute fuel, is very difficult to foresee, because alcohol is a single product, whereas engine fuel from petroleum or shale oil is tied up with other necessary products, such as lubricants. This relationship would seem to indicate that shale oil distillate *must* come on the market, whereas alcohol *may*. However, so long as petroleum and its successor can meet the demands it will be difficult for any product, single-handed, to come in and compete, for the simple reason that when you produce a series of joint products you can sell one of them as cheaply as you please by shifting the price of the others. This circumstance has a very practical bearing when a product like alcohol tries to displace gasoline.

CHARLES B. PAGE:—Will Dr. Pogue discuss the characteristics of the heavier oil which the tractor may be obliged to use some time in the future, or should be prepared to handle successfully?

DR. POGUE:—Half of the petroleum at the present

Digitized by Google

time is turned into fuel oil, which is a product heavier than kerosene. The development along that line will mean the development of an engine radically different from the present type of engine, such as the Diesel or semi-Diesel. Whether such an engine is applicable to tractors I am not prepared to say, although quite probably it is. There are possibilities of great promise, too, in connection with the gas turbine, which, if I understand the matter correctly, can use practically any type of liquid fuel. The situation depends entirely upon how far the internal-combustion engine has been developed toward ultimate perfection. I rather like to take the view that even these mechanical matters are in course of evolution, and if you recall the length of time that elapsed between the first crude steam engine and the present efficient steam turbine, you will see that the internal-combustion engine, at least as regards its intensive period of development, is still very immature. Moreover, up to the present there has been absolutely no incentive, no economic reason, for the internal-combustion engine to develop in the direction of increased fuel economy or in the direction of using a less volatile fuel than gasoline, because there was plenty of cheap gasoline. We are just at the present time beginning to meet a different situation, where the pressure shaping the evolution of the internal-combustion engine is of a different kind. The internal-combustion engine seems to me to be a very notable achievement; indeed, one of the outstanding accomplishments of the twentieth century, but its attainments have been in the direction of flexibility, power, ease of operation, and so on, and have not taken the direction of fuel economy and efficiency, for the very simple reason that there has heretofore been no cause for development in that direction. Now, if a cause has arrived, as I believe it has, the engine will follow that course of development. I believe that the time has arrived in American economic practice when we can use our knowledge for seeing these things in advance, and, by planning ahead, make a gain over what we would have if we left things to their normal untrammeled course of development. It seems to me that is what science is for.

MR. FOLGER:—Is it not possible that shale oil can be separated by distillation processes or by cracking into fuels suitable for the automotive industry?

DR. POGUE:—It is very probable that shale oil will

Digitized by Google

yield roughly the same range of products that petroleum does.

MR. FOLGER:—Is it not true that the shale field offers an almost equal supply to our present fields when fully developed?

DR. POGUE:—The quantity of oil which the oil-shale deposits in this country are capable of producing is astounding. I started to say that the petroleum resource looks insignificant compared to the oil-shale resource. There are centuries of oil in shale, but you must remember that the production of oil from a lean resource like oil shale, which has to be mined and then distilled before you get it to the state of crude petroleum, means that the products, in all probability, can come on the market only at a much greater production cost than that of petroleum. Otherwise, they would be on the market today, and they are not. Petroleum is a creamlike resource, and so long as we can go out and drill a hole in the ground and have oil come out so rapidly that we can scarcely take care of it, shale oil means nothing. When that period is over shale oil will come in, but we have a more expensive proposition to meet there, and can meet it very easily by merely increasing thermal efficiency. I was surprised, when I first went into this matter. I had a suspicion that the internal-combustion engine was not as efficient as it might be in respect to fuel economy, but on every hand competent automotive engineers tell me that it would be possible to double or treble, or even quadruple, the mileage obtained from engine fuel, not exactly in the present engine, but by devoting attention over a period of years to that result. If that be the case, as these greater production costs come in they can be tempered and nullified by increasing the efficiency of the internal-combustion engine. There is a give-and-take relationship between the engine on the one hand and fuel on the other, and we will not get the maximum economy until those two things are brought into coordination. If there were one big industry in this country producing all the oil and making all the engines, there would be no fuel problem at all, but such is not the case. We have the oil industry, which is composed of a number of units, and we have the automotive industries also composed of a number of units. They are competing. They can cooperate only with difficulty, yet for a favorable outcome they must be coordinated. We have come to the time when this

Digitized by Google

question of coordination must be settled, and it seems to me that a function as large and as embracive as that cannot be carried on by any other agency than the Government. I conceive it to be the duty of the Government to stand ready to effect the coordination of technology, without which proper progress cannot take place; and, moreover, without which this country cannot keep pace with the European countries which are doing or are planning to do this very thing.

MR. FOLGER:—If the engine builder designs a more efficient engine, and the oil fields produce double, treble or quadruple the amount of shale oil from the shale fields, the result will be an item in the automotive industry. It is merely a matter of price that is keeping them out.

DR. POGUE:—In 10 yr., if not sooner, I expect to see a large production of shale oil. The fact that it will cut a figure in the future does not necessarily affect the situation today, because so far as the present is concerned we may regard shale oil as part of the petroleum resource. All that shale oil does is to assure us that there will be plenty of oil, but it does not assure us that there will be cheap oil. There is no danger of exhaustion. Shale oil will last for many centuries. We need not be pessimistic on the question of exhaustion. It is simply a matter of securing more or less economy, which means everything. If a man cannot afford an automobile at a certain price of engine fuel it means everything to him whether that fuel is above his level or below it.

MR. FOLGER:—It is well known that the cost of fuel as a part of the total operation of a car is very small. It is one of the smallest items in the cost of passenger cars.

DR. POGUE:—In the event of the cost of fuel doubling it becomes twice as important.

MR. FOLGER:—Even at that it is very much less than the cost of tires, supplies, etc.

MR. WALKER:—A man will buy a passenger car, and it does not make any difference what it costs him to run it. When he buys a car to do business with he very carefully analyzes the cost.

DR. POGUE:—According to the figures we gathered, the average fuel consumption in running a motor truck is 47 bbl. per yr., and at $8 per bbl. the annual fuel cost is a considerable item.

HERBERT CHASE:—It is very apparent that gasoline will

Digitized by Google

not always be available in the form that we know it today, although we may have it at a price very much greater than we now pay. Is it not obvious that the automotive industry as a whole should immediately undertake the development of engines that will use a wider range of fuel? These may not be Diesel engines, they may be an entirely different type, one that does not run on cycles, but I firmly believe that it is the duty of the automotive engineers of the country to undertake this task at once. Some years ago it became evident that a very fine grade of coal, that is a pulverized form or the smaller sized lumps, could be used for steam purposes. It was thought that this would effect great economy in the coal supply. As a matter of fact, since the coal could be had at a lower price, the demand was so much greater that within a few years the fact that a larger source was available had been offset. It seems to me most important that engineers today realize the need for increasing the thermal efficiency of engines and seeking for one that will adapt itself to a wider range of fuels.

C. J. P. LUCAS:—Fuel is a vital factor in the sale of tractors, trucks and passenger cars in South America, and it is absolutely necessary, if American manufacturers want to get their share of that business, that they be able to design an engine that will burn almost any kind of fuel. The people at Buenos Aires pay between 62 and 75 cents per gal. for gasoline. That is the one factor that is keeping American and all other tractors out of the South American markets. Until American manufacturers design an engine that will burn a low grade of fuel which will not cost over 30 cents per gal. they will have a hard time getting a fair share of that trade, because the South Americans are very loath to change.

Digitized by Google

FUEL ECONOMY OF AUTOMOTIVE ENGINES

By Dr H C Dickinson[1]

THE approaching exhaustion of the petroleum supply, from which nearly all of the available internal-combustion engine fuel is produced, raises two vital questions, upon the answers to which will depend the future of the automotive industry. These are (*a*) what fuels are to be available, from the point of view of the engine designer and (*b*) how much transportation can be secured from the fuel used.

It is not certain that satisfactory engines can be developed to handle a wider range of fuels than those used at present. It is therefore not clear whether the trend of development will be toward two or more different grades of fuel, or toward a single mixed fuel to be used in all engines ultimately designed to burn it. The development of different grades of fuel may result in a light fuel, such as gasoline, and a heavier fuel, such as kerosene, or an even heavier product, each to be used in engines of different designs, the heavier-fuel engine being used for tractor and possibly truck service.

The second question emphasizes the necessity of more careful study of the fuel waste in existing types of vehicles. A brief analysis of present automotive practice shows that not less than 30 per cent of the fuel is used unnecessarily. Bad carburetion, largely due to ignorance or carelessness on the part of the user; excessive mechanical losses, and a general tendency to heavy cars and unnecessarily large engines, are responsible for this condition. A more careful scientific study of fuel economy is urgently needed.

The subject of fuel economy in automotive engines has been of such secondary importance as to appear mainly of academic interest. Fuel costs in this country have not yet become of primary importance in the maintenance of passenger cars and seldom so in the operation of commercial vehicles. Questions of first cost, reliability, flexibility, and in the case of passenger cars, ease and comfort of operation, in other words, luxury, have been of far greater commercial importance.

There has been a decided though gradual increase in

[1]Bureau of Standards, Washington.

Digitized by Google

the importance of fuel costs in the last few years. This is due partly to the increase in the cost of gasoline relative to that of other items in the total bill for operation of motor vehicles and partly to the stabilization of the industry, which always leads to more and more careful consideration of all items of expense.

That the relative importance of fuel costs, particularly as regards commercial vehicles, will increase at a growing rate from now on is inevitable. This is readily seen on a careful analysis of the situation as to fuel supply. The extent and success of the automotive industry will depend upon the amount and price of available fuel, and the cost per ton-mile or ton-mile per hour of transportation.

This then raises the questions which the automotive engineers must face, and face immediately: (*a*) What are to be the available fuels from the point of view of the engine designer? and (*b*) How many ton-miles or ton-miles per hour can be obtained from the total available supply?

The Fuels of the Future

The answer to the first question, i. e., what are to be the available fuels, will depend upon the possible flexibility of automotive engines as regards the use of less volatile or perhaps impure or mixed fuels not now available. Of course, alcohol, benzol and shale-oil distillates may add increasingly to the supply of fuel of approximately the present grades of volatility; yet it is imperative that the industry should fully appreciate the necessity of much further development in the use of less volatile fuels and perhaps of special fuels to meet future requirements. The properties of fuels at present recognized as important and subject to specification and test are as follows:

(1) Volatility, determined by distillation. The characteristics of the low boiling fractions determine the ease of starting of any given engine. The characteristics of the high boiling fractions indicate the tendency to incomplete combustion and to contamination of lubricating oil

(2) Resin values determined by gumming tests which determine the liability of the fuel to leave objectionable gummy deposits in the carbureter or on valve-stems, etc.

(3) Heat of combustion in British thermal units determined by a combustion calorimeter. The heat

Digitized by Google

of combustion determines the total available energy supply in any given fuel. Differences between different gasolines do not exceed 2 or 3 per cent. Fuels of widely different heats of combustion (gasoline and alcohol) give corresponding differences in pounds per horsepower-hour. As between different gasolines in use, these relative differences are not apparent

(4) Presence of unsaturated hydrocarbons determined by chemical treatment specified by the Bureau of Mines. The presence of these compounds does not affect the power-producing qualities of the gasoline so far as is at present known

Other properties not commonly determined by test but which may be important are as follows:

(1) Vapor pressure, which is closely related to volatility, is probably important as regards the starting qualities of fuel

(2) The product of vapor pressure by fluidity offers a means of estimating the occurrence of different constituents in a gasoline

(3) Viscosity which usually varies with the temperature and composition of the fuel. Changing viscosity affects the metering characteristics of most carbureters

(4) Saturation, pressures and temperatures for fuel-air mixtures in combining proportions. These relations may be important in determining the temperatures at which complete vaporization of the fuel in the intake can be secured

(5) Rate of flame propagation. It is important in the selection of fuels for high-speed operation and also determines to some extent the thermal efficiency which can be obtained

(6) Detonation is of importance in determining the maximum compression pressures at which any given fuel can be successfully used

(7) The products of combustion occurring during the process, if determined, would probably throw light upon the causes of detonation and help to explain the different characteristics of different fuels

Engine characteristics which have a bearing on the behavior of different fuels are as follows:

(1) Compression ratio, which is limited by the tendency of the fuel to preignite or to detonate. The production of fuels which resist preignition or detonation would permit of considerable increase in

Digitized by Google

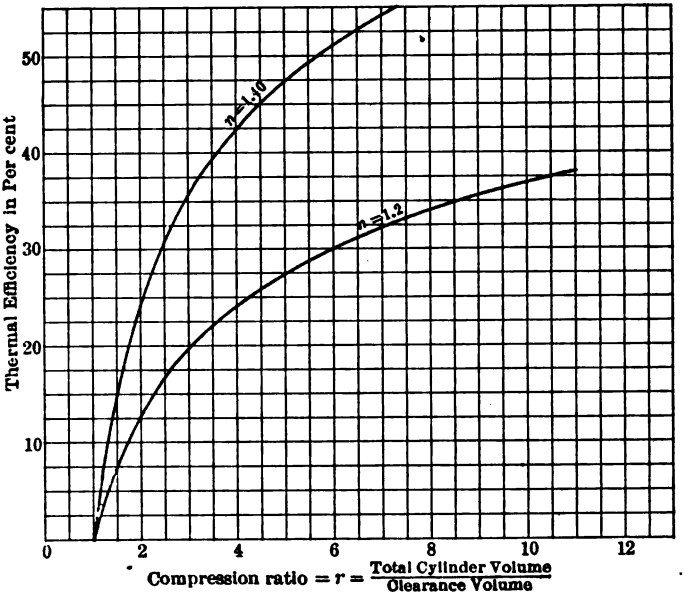


FIG. 1—RELATIONS BETWEEN THERMAL EFFICIENCY AND COMPRESSION RATIO IN AN INTERNAL-COMBUSTION ENGINE

compression ratio and corresponding increase of thermal efficiency. (See Fig. 1)

(2) The design and dimensions of the explosion chamber or the ratio of surface to volume affect the tendency of a fuel to preignite as they do the thermal efficiency of the engine

(3) Localized hot spots occurring, for instance, on spark-plugs, piston heads or valves, affect preignition

(4) Engine speed in revolutions per minute. The speed at which an engine can be run with satisfactory thermal efficiency depends upon the rate of flame propagation and other characteristics of the fuel

Some problems which are of interest in the study of fuels are as follows:

(1) The effect of varying fuel composition on brake thermal efficiency of engines of different types. Some measurements of this kind are available for maximum load conditions, but scarcely any for engines operating at low throttle

(2) The phenomenon of detonation which occurs persistently with some fuels and much less so with

Digitized by Google

others is of prime importance. Its cause and possible remedies should be given additional study

(3) The commercial development of fuels which will permit of increased compression pressures. Such fuels as cyclohexane and benzol-gasoline mixtures offer a promising field of investigation

Another question which appears to be worthy of careful consideration is this: In the use of fuels of a wide range of volatility, will the best overall economy be secured by developing apparatus to use a single very heterogeneous fuel such as would be represented by a mixture of gasoline, kerosene and perhaps heavier fractions; or will this same end be best attained by developing two or more distinct types of appliances, and consequently the marketing of two or more distinct and semi-standardized fuels? The more volatile of these would not be used to any extent in appliances fitted for the less volatile grades on account of cost, fire risk or other causes.

There is much to be said on both sides of this question, which should be settled as a matter of fixed policy by the automotive and the oil industries jointly. If these industries are allowed to pursue their course of natural development without such a directing policy the ultimate solution is likely to be long delayed and will result in great expense to all concerned.

The Lines of Development

The present trend of development seems to point to the use of two or more fuels. We have as semi-standardized products, gasoline and kerosene, and a trend of development toward devices intended specifically to utilize one or the other. While most of the kerosene devices will still use gasoline as well or better than kerosene, this may be attributed to the fact that most of these devices are direct lineal descendants, so to speak, of gasoline devices and to the fact that the trend of commercial gasoline has been to encroach more and more on the kerosene field. If future carbureters are developed and widely adopted which will handle kerosene and heavier distillates better than they will gasoline, there will be a strong tendency to make gasoline and kerosene more distinct in character than at present, i. e., there will be less necessity of including the heavier fractions in gasoline or passenger car fuel, as they might be marketed at nearly the same price in the heavier grade of fuel.

Digitized by Google

The advantages to be gained by this line of development are as follows:

(1) It would permit the unrestricted use of most of the present existing carburetion equipment for its entire useful life, since there would then be no necessity for any further considerable reduction in quality of gasoline

(2) It would permit a permanent use of the more volatile fuels for those types of service where inconvenience, flexibility or luxury are important, such as airplanes and passenger cars, and of a less volatile and somewhat cheaper and much safer fuel for most commercial purposes

(3) It would offer a real advantage from the engineer's standpoint in not calling for the design of all equipment to meet the most difficult carbureting condition. There is no question that the use of kerosene and heavier fuels in engines of the present type presents to the engineer a difficult problem which is likely to be solved much more satisfactorily for commercial cars than for passenger cars. The heating of the inlet charge which at present appears essential to the use of heavy fuels, necessarily decreases engine power, thus requiring a larger and therefore heavier engine to deliver the same maximum power. This is accompanied by increasing friction losses which are extremely important at the average light-load conditions obtaining in passenger cars. The average engine load is probably much nearer the maximum in all commercial vehicles

(4) The quality of two fuels could probably be maintained more nearly uniform than that of a single fuel, as there would be greater opportunity with two grades for the refiner to adjust the distribution of the fractions of his total product to accord with the demands of the user

Offsetting these advantages made possible by the use of two distinct types of fuels, there are decided advantages to be expected from the adoption of a single fuel for all automotive engines:

(1) The cost of production and distribution of a single fuel would be less than that of two

(2) All automotive equipment would be standardized eventually to handle the same universal fuel

The foregoing discussion has been based on the present general type of engine, i. e., the four-stroke Otto cycle,

Digitized by Google

constant-volume engine, water-cooled, and supplied with throttle-controlled, carbureted mixture. That this almost universal type may be replaced by something else in the interest of fuel utilization is not beyond the bounds of possibility. Other types, such as the Diesel, with fuel injection, are better adapted to the use of heavy fuels, are more flexible in the kinds of fuel which they will use, and may offer other advantages in economy. If a radically different type of engine should be developed along these or any other lines, or if for instance a steam engine, some of which show thermal efficiencies equal to that of present automobile engines, viz., above 20 per cent, or a combustion turbine, should ultimately be widely adopted, the advantages of a single fuel would be increased.

Fuel Economy

The second main question, i. e., how many ton-miles or ton-miles per hour, or tons drawbar-pull miles, can be secured per gallon of fuel, may best be considered by a general survey of the energy distribution in the operation of automotive appliances.

The automotive vehicle, whether it be passenger car, truck or airplane, is essentially an appliance for transforming stored heat energy into useful work in the form of transportation in ton-miles or ton-miles per hour. In tractors the useful work may be represented by ton drawbar-pull miles. It is interesting to note that trucks and passenger cars deliver approximately the same number of ton-miles per hour for the same heat supplied on the basis of the total weight of the machine.

Table of Figures

Trucks	0.57 ton-miles per hr. per hp.
Passenger cars	0.47 ton-miles per hr. per hp.
Airplanes	0.58 ton-miles per hr. per hp.

Granting that the object to be gained, so far as fuel is concerned, is the maximum number of ton-miles, or for some purposes ton-miles per hour, per unit of available heat under average operating conditions, it is of interest to arrive at some estimate as to what becomes of the heat supplied by the fuel burned under these conditions.

Fig. 2 represents the average of a number of familiar published analyses of heat distribution in passenger cars at approximately full load and most favorable speed with

Digitized by Google

most favorable road surface. This may serve as a basis for discussion of the various items involved.

Fig. 3, presented for illustration, gives the results of experiments with an Hispano-Suiza aeronautic engine

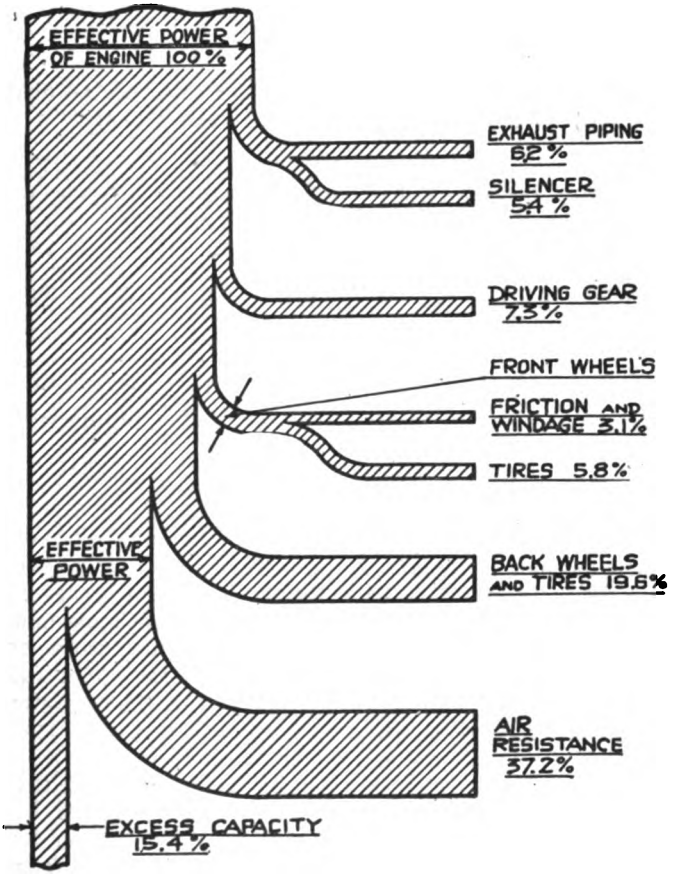


FIG. 2—ENERGY DIAGRAM FOR SPEED OF 38 MILES PER HR.

tested in the Altitude Laboratory of the Bureau of Standards.

The following table gives the heat distribution for motor vehicles: (Some of the figures for passenger cars have been estimated)

Digitized by Google

	Full load and most favorable laboratory adjustment, per cent	Average load and speed laboratory adjustment, per cent	Average load and speed, average operation adjustment, per cent
Heat supplied	100	100	100
Cooling water	36	38	38
Exhaust	36	39	43
Engine friction	6	13	13
Brake thermal efficiency	22	10	6

Of the available power of the engine, also of the heat supplied, the distribution is somewhat as follows:

	Good practice		Average practice		Bad condition	
	Engine power, per cent	Heat supplied, per cent	Engine power, per cent	Heat supplied, per cent	Engine power, per cent	Heat supplied, per cent
Muffling	9	2.0	10	1.0	10	0.6
Driving gear..	12	2.6	15	1.5	18	1.1
Tires (on best roads)	23	5.1	30	3.0	35	2.1
Road surface (added load)	0	0	5	0.5	12	0.7
Useful power	56	12.3	40	4.0	25	1.5

Let us consider these items individually, beginning with the brake thermal efficiency.

Brake Thermal Efficiency

The present brake thermal efficiency of the best aeronautic engines is roughly 25 per cent running up to perhaps 28 per cent or a little higher in extreme cases at full load and the most favorable speed. The maximum thermal efficiency of the modern automobile, truck or tractor engine will seldom exceed 20 per cent under full load and most favorable speed conditions. The greater part of all gasoline is, however, consumed in engines running under very much less favorable conditions.

If it is assumed that the average passenger car in this country is capable of a road speed of 45 miles per hr. and is operated at an average speed of 20 miles per hr. then the tractive load in pounds is probably not far from one-fourth maximum tractive load and the engine speed is about one-half the rate. The average car as now built is, therefore, necessarily being operated under conditions which absolutely preclude an engine brake thermal efficiency exceeding something between 10 and 15 per cent; probably very much nearer 10 per cent than 15 per cent.

This figure again represents not what the average car is doing, but simply the best that it could do under the

Digitized by Google

average speed and load conditions if supplied at all times with the most efficient fuel-air mixture, which unfortunately is seldom the case. How far the present average carbureter adjustment is from the best possible one is not now known. As an illustration of what may be the difference between the possible and actual average fuel consumption, Fig. 6 gives "miles per gallon" as measured on a standard Ford engine mounted with a fan load, adjusted to give a speed corresponding to 40 miles per hr. car speed at full load. Car-speed load relations are computed from previous data on power requirements of cars on a level road. These results are in accord with what we know of the performance of cars of this kind, and are probably representative of what is happening with Ford cars on the road, and Ford cars are responsible for the consumption of a large share of the gasoline used.

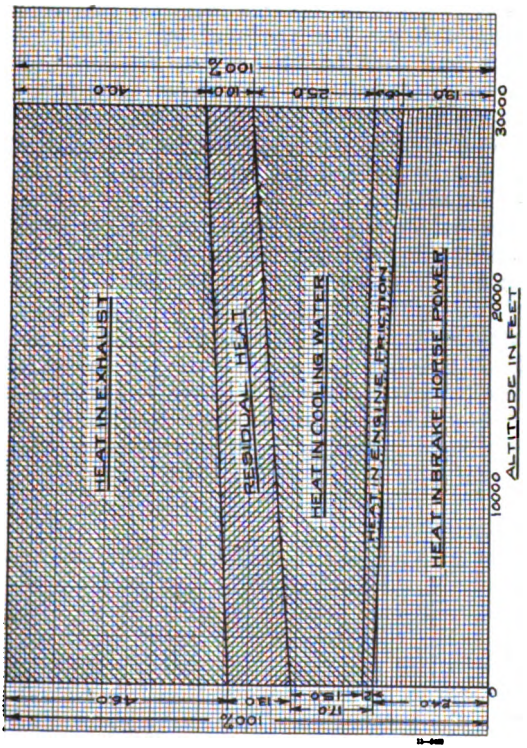


FIG. 3—HEAT DISTRIBUTION AT VARIOUS ALTITUDES IN A 150-HP. HISPANO-SUIZA AIRCRAFT ENGINE

Digitized by Google

Briefly stated, the average passenger car is running on an average mixture ratio somewhere between 25 and 50 per cent richer than is necessary, with consequent increase in carbonization and in lubrication difficulties, and with no attending advantages except possibly greater ease in starting and quicker get-away when the engine is cold.

The scores of "pills," "improvers," and "dopes" sold to the unsuspecting public and guaranteed to increase the car mileage anywhere from 20 to 100 per cent bear eloquent testimony to the failure of passenger vehicles in particular to reach their maximum fuel economy. There is, of course, no known substance commercially available which can be mixed with gasoline in the proportion of 1 in 5000 or even 1 in 500 with any significant effect on engine power. Probably no such substance exists. Whether any substances in such small amounts can reduce the deposition of carbon is difficult to prove conclusively, but there is no reliable evidence that even this can be accomplished. Yet the engineers must face the incontestable fact that fuel improvers are sold and that changes in engine condition, carbureter adjustment and carefulness of the driver, etc., which accompany their use, do account for actual increases in average mileage per gallon, even when full discount is made for the psychological element.

In the recent *New York Herald* 1000 mile track and road test, neglecting the necessary uncertainties of any such test, some eleven cars did actually attain an average mileage of 19.8 miles per gal., and these same cars with modified attachments and adjustments made an average mileage of 28.6 miles per gal. This was accompanied with no significant decrease in acceleration or flexibility, if the records are to be taken at their face value. While no engineer could accept without qualification the conclusions drawn from a test of this kind, the figures given illustrate at least the possible differences in fuel economy which can occur in practice.

One cannot escape the conclusion that the average car could be made to cover at least 20 per cent more miles per gallon than it does today. In other words, sufficient engineering skill, if applied at this point, could conceivably increase by 20 per cent our available fuel supply; or, in other words, permit an additional 1,000,000 cars to operate on the present gasoline consumption.

The demand for cars characterized by easy starting and

Digitized by Google

quick get-away with a cold engine, is responsible for a large part of this excess fuel consumption; and considered from the point of view of the automobile industry when facing a probable limitation of fuel, this ease of starting is expensive at the price. The development of better means of starting and warming an engine

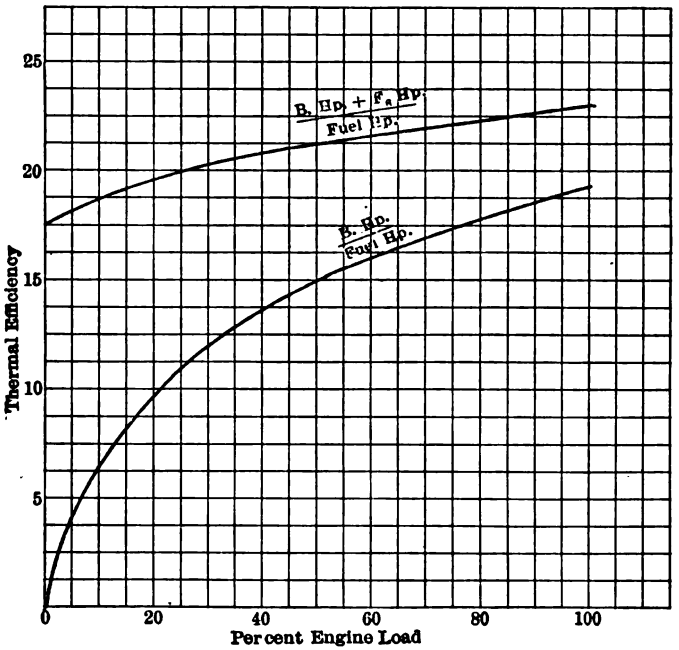


FIG. 4—BRAKE THERMAL EFFICIENCY OF A CLASS B TRUCK ENGINE OPERATING AT 1000 R.P.M.

seems to have been neglected, except as regards convenient means of turning the engine over. The writer believes that this is an undeveloped field in which a reasonable amount of engineering ability might yield large returns to the successful inventor, and incidentally benefit the whole industry enormously by removing one of the main obstacles to better average fuel economy. However, the owner and the garage man are not responsible for all the fuel waste.

The subject of carburetion opens a field for unlimited discussion. In spite of the enormous amount of develop-

Digitized by Google

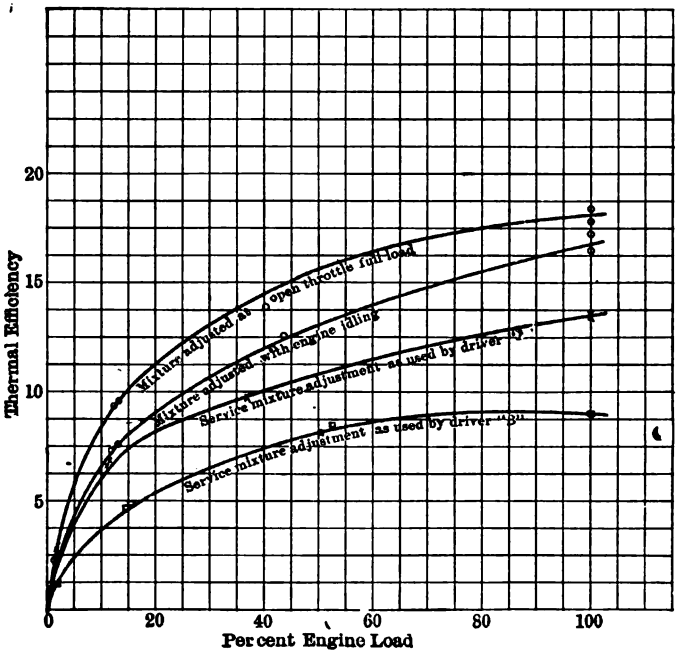


FIG. 5—BRAKE THERMAL EFFICIENCY OF A FORD ENGINE

ment work done in this field, the art of metering and mixing fuel and air, even considering commercial gasoline alone, has not kept pace with the development of the engine and the changing quality of gasoline. There is no doubt that a more nearly universal application of carefully worked out engineering laboratory tests on all carbureters, over their full range of performance, would lead to decided improvements and perhaps to the elimination of some designs which cannot be made to give uniform results. Without attempting to discuss this field of design, the writer ventures to urge the importance of at least the abolition of the present common practice of supplying carbureters with a wide range of adjustment which the ordinary garage mechanic or the owner can manipulate to suit his own fancy.

The carbureter, so-called, is essentially a device for metering and atomizing fuel and mixing it intimately with the measured quantity of air required by the throttle opening. So far as metering alone is concerned, there is no serious difficulty in producing a non-adjust-

Digitized by Google

able carbureter for all kinds of service. The only difficulties occur at very light loads and with extreme temperature changes. Numerous successful methods of metering properly at low throttle are in use. The effect of changes in temperature or quality and consequent changes in viscosity of the fuel can be minimized by the use of types of metering orifices in which the rate of discharge is least affected by viscosity.

As regards atomizing and mixing, the adoption of a non-adjustable design presents no serious difficulties. The general adoption of the best available non-adjustable carbureters would effect a very important saving in fuel. A more general adoption of accurate laboratory methods for development tests may be depended upon to bring out designs which will meet all requirements with still greater economy of fuel.

Exhaust Losses

The heat in the exhaust gases represents with complete combustion in general about 40 to 45 per cent of the total heat of the fuel burned in the cylinders. If

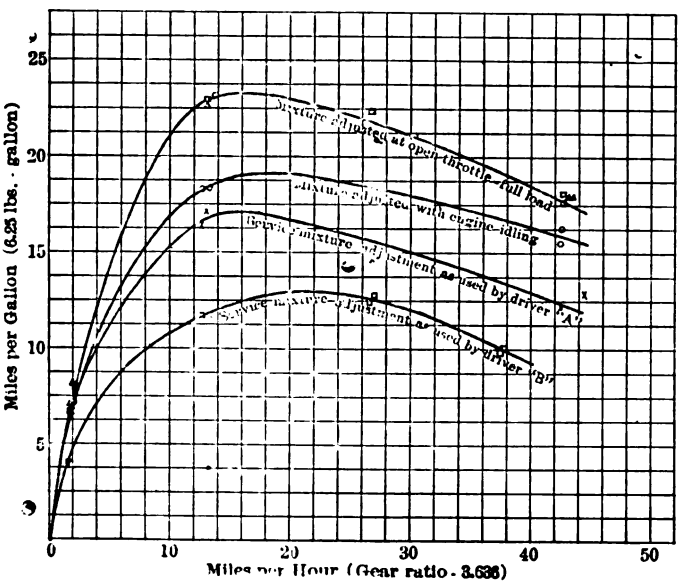


Fig. 6—Curve of Fuel Consumption and Speed for a Ford Engine Using Various Mixtures

Digitized by Google

the fuel charge is *completely* burned early in the power stroke, the exhaust heat is determined by the total heat of the fuel burned, the compression ratio, and the loss to the jacket. With perfect carburetion, including both vaporization and mixing of the fuel and air, and with proper timing of ignition, this loss is a minimum.

In practice, however, the atomization of fuel in the carbureter is usually not complete enough to permit of complete combustion early in the power stroke and the exhaust usually contains considerable heat due to delayed combustion of some of the fuel, as well as considerable unburned or partially burned fuel. These losses probably represent the largest remediable waste of fuel in automotive appliances. If this waste alone could be eliminated, certainly at least 500,000 additional passenger cars or their equivalent, possibly twice this number, could be operated on the gasoline which would be saved.

Cooling Water

The cooling of cylinder walls is apparently essential, but the loss varies so much that a careful study of its causes is important. Unlike losses in the exhaust, it is subject mainly to mechanical, not therodynamic, limitations, and, in theory, at least, might be greatly reduced.

Transfer of heat from the hot charge to the cylinder walls takes place both by conduction and by radiation from the hot gases to the cooler cylinder walls. As the gases themselves are transparent to radiation, the amount of heat received per unit area of cylinder wall depends not only on the temperature but on the depth of the radiating gas charge or, in other words, on the cylinder volume.

The percentage loss to cooling water for a given mean effective temperature of charge depends upon turbulence, cylinder design and dimensions, piston speed and cylinder wall temperature. The latter is less important than might appear, since the effective temperature of the charge is so much higher than that of the walls (the difference being probably well over 2000 deg. fahr.) that differences of 100 to 150 deg. such as may occur in cylinder wall temperature are not very important as regards jacket water losses.

Three possibilities for a radical decrease in cooling jacket losses are:

(1) Reduction in the ratio of surface to volume in the combustion chamber

Digitized by Google

(2) Reduction in the mean effective temperature in the cylinder without too great loss of efficiency of the cycle

(3) The operation of engines with cylinder walls very much hotter than at present

As has been pointed out above, the walls would necessarily be very much hotter than is possible under existing conditions to offer any considerable advantage in reduction of jacket losses. However, a moderate increase in temperature may improve fuel economy and lubrication as well as prevent the deposit of fuel on the cylinder walls.

Reduction in mean effective temperature, on the other hand, offers some practical possibilities. For instance, in fuel-injection engines, direct and semi-direct types, the cycle efficiency might be maintained with very moderate temperature within the cylinders. The mechanical efficiency, however, tends to be low under these conditions.

Friction Losses

The friction losses in engines are usually from 10 to 20 per cent of the brake power developed by the engine, or from 2 to 4 per cent of the heat supplied. Any reduction in these losses, however, will increase the available power of the engine and permit the use of smaller units on account of the relatively large amount of power absorbed in friction at light engine loads. The friction losses comprise those due to (*a*) the work necessary to compress the charge from the intake pressure to that of the exhaust, (*b*) the friction of the reciprocating and rotating parts of the engine, the piston, valves, camshafts and crankshafts, and (*c*) the power necessary to drive the auxiliary apparatus, the ignition and lighting systems, the fan and water-pump, etc. Of these losses, that due to the compression of the charge is the most important, being in some cases as much as 50 per cent of the total friction loss.

The losses due to the compression of the gas charge are inherent in the method of throttle control of the engine and can be eliminated only by a fundamental change in the cycle used or means of control. The possibilities of reducing the losses in the rotating parts with properly lubricated bearings are slight, but any losses due to excessively viscous or otherwise unsuitable lubricant are entirely unnecessary and can be avoided at all times.

Digitized by Google

Muffler Losses

Losses in manifolding and muffling are of some importance at full load and high speed, being, according to Riedler, about 9 per cent of the total power. This figure is probably much too high for current American practice, since manifolding losses are decreased, although no very satisfactory test figures are at hand. The Galain muffler shows much better results. However, the relative muffler losses decrease considerably at light loads, so that under average road condition they are not of great importance.

The problem of muffler design might repay further careful investigation by a small gain in economy. In an exhaust manifold which connects not more than six cylinders, there occur pulsations whose kinetic energy may be utilized to reduce back-pressure at the end of the exhaust stroke. Mufflers which seem to utilize this effect have been designed, and their more general use might be advantageous.

Driving Gear Losses

The fact that losses in transmission amount to 12 per cent of engine power, according to Riedler, are in general difficult to measure accurately and require elaborate equipment for the purpose, probably accounts for the comparatively few investigations of transmission gear efficiencies that have been undertaken. Moreover, much of the best information that has been obtained is lost in the files of the experimental departments of manufacturers.

Although the possible fuel savings which might be accomplished by refinements in transmission systems are not so great as from improvements elsewhere, they do have a direct bearing on lubrication difficulties and expenses, since unnecessary power losses in transmission are accompanied by unnecessary deterioration of lubricants due to high temperature, etc. Tight gearcases permitting the use of oils of properly low viscosity allow considerable reduction in this item of loss. On the whole, the subject is one which offers a fertile field for investigation, with prospect of most attractive returns from a small outlay for careful research work.

Tire and Road Surface Losses

Power losses between the wheel rim and the road, while of considerable importance, representing 15 per

Digitized by Google

cent or more of the engine power, are perhaps less understood than any other important item of vehicle efficiency.

Some results have been secured relative to the losses of different types of pneumatic tires at different inflation pressures on experimental surfaces; and some comparative road tests on both pneumatic and solid tires have been run on various kinds of road. Many of these tests have been undertaken by tire makers or road makers, and in road tests which involve so many elements of uncertainty and psychology that it is not easy to avoid some bias on the part of interested parties.

The following table of results illustrates differences in mileage which may occur with trucks on different types of road surface. It is quoted from an article published by A. N. Johnson in the *Engineering-News Record*, Nov. 7, 1918. The tests were run with five new White 2-ton trucks under conditions which appear from the published description to warrant full confidence in the results quoted.

Figures are given in gallons of fuel per truck-mile and in percentage of the fuel used on brick or concrete roads with no load. The table, therefore, shows the additional fuel consumption due to poor road surface as well as to increased load. "Commercial runs" were made at varying speeds averaging about 15 miles per hr.

A systematic collection and analysis of all existing results regarding power losses at the road surface, prepared from the point of view of the engineer interested particularly in overall efficiency, would yield further valuable results. Incidentally one of the most important, if not the most important, phase of this subject deals with highway engineering rather than with automotive engineering. Only by the closest cooperation between the automotive and highway engineers and the tire manufacturers can this problem be solved successfully.

Useful Power

Under most favorable car and road conditions, at full load and most favorable speed with passenger cars as now constructed, probably a little more than 50 per cent of engine brake horsepower may be available for driving the car, for overcoming grades and air resistance. Under average conditions, this percentage is reduced from 35 or 40 per cent. Thus, only between 5 and 10 per cent of the total heat available in the fuel appears as

Digitized by Google

Road Surface		Speed 15 Miles per Hr. on Third Gear				"Commercial Run" on Fourth Gear			
		Trucks Empty		Trucks Loaded with 2 Tons		Trucks Loaded with 2 Tons		Trucks Empty	
Type	Condition	Gas, gal.	Per cent.	Gas, gal.	Per cent.	Gas, gal.	Per cent.	Gas, gal.	Per cent.
Earth	A little mud, generally fair	0.1331	156	....	...	0.1730	204	0.1022	138
Gravel	Fair	0.1121	132	....	...	0.1390	164	0.0918	124
Gravel	Good	....	...	0.1433	151	0.1063	125	0.0878	119
Bituminous macadam	Somewhat worn and uneven	0.0967	114	0.1056	111	0.1054	124	....	...
Brick	Fair to good, somewhat worn	0.0980	115	0.1050	111	0.1012	119	....	...
Brick (paralleling first section) ...	Extra good	....	...	....	...	....	...	0.0738	100
Brick	Good, extra smooth.	0.0850	100	0.0949	100	0.0875	103	....	...
Concrete	Good	0.0851	100	0.1017	107	0.0849	100	....	...

Digitized by Google

useful work in transportation. None of the individual factors in this loss of 90 to 95 per cent can be eliminated; but most of them can be reduced by better engineering, and by educating the public. To eliminate 10 per cent of the aggregate waste would be equivalent to doubling the fuel supply under present conditions. With these possibilities in view a real fuel shortage will not occur for some time if means are taken immediately and systematically to accomplish all possible economies as promptly as possible.

Conclusions

The foregoing discussion of familiar features of engine and vehicle design, presented from the point of view of ultimate economy of fuel suggests a group of fundamental research problems on most of which more or less careful work has already been done. Much of this work, probably most of it, is not readily available, and even if it were, it does not represent any approach to a final solution of any one of the problems presented.

The automotive engineers have worked together perhaps more than any other group of engineers in solving problems of the industry. The next and all-important problem of fuel economy can be solved only by more complete and exhaustive research than has been undertaken heretofore. Nor can this be accomplished by either the automotive engineers alone or by the refiners of petroleum and other fuels. The writer wishes to urge therefore more active and effective cooperation between the two industries in attacking this important problem. For this purpose there is an urgent need for the formation of an organization of petroleum technicians which would be in a position to collaborate with the automotive engineers in a joint study of fuel production and utilization.

No one company and no one laboratory can hope to undertake effectively more than a very small part of the necessary research. Some means, therefore, should be provided for directing and coordinating for the industry in general such work as can be undertaken by the experimental departments of manufacturing companies and by the various laboratories equipped for these lines of research. This is a field in which every engineer and manufacturer will profit most by the general distribution of all available information.

Recognizing that the saturation point, so to speak, of

Digitized by Google

the country for motor vehicles depends ultimately upon the amount of fuel required to operate the average vehicle, the gain of 20 to 40 per cent in economy which may be reasonably expected as a result of a systematic research program represents a profit to the industry compared with which the cost of the research would be totally negligible.

THE DISCUSSION

F. C. MOCK:—If we are discussing the problem of fuel economy with reference to fuel consumption in this country in the 5 or 6 yr. just before us, it is obvious that we must take into consideration the operation of engines already built or those which will be built within the next 2 or 3 yr., according to present or older designs. Improved design will not have a great effect upon the general fuel consumption of the country for several years.

As regards tire and road surface, driving gear and friction losses, I have regularly followed the practice of estimating the power required to drive a car by noting the time required for deceleration while coasting. This time of deceleration is an indication of the road and mechanical friction of the car per unit weight, and I have been surprised to note that a great many different cars, of various prices, designs and ages, after the first 2000 miles of service, all seem to have about the same drawbar pull per ton weight, either coasting with a free clutch, or with clutch in, spark off and throttle wide-open. This would indicate that the friction and road losses of present-day cars in use do not vary greatly. This statement does not apply to Fords.

I do note a considerable variation in the rate of deceleration with clutch in, spark off and throttle open to the position required to drive the car at 20 miles per hr. on a smooth road. By the use of a large gear reduction, such as is common practice at the present time at speeds of average driving, there is a high vacuum in the intake manifold and in the cylinder during the intake stroke. This vacuum is about 7½ to 8 lb. per sq. in., and on the intake stroke gives rise to lost work. The mean effective pressure required to drive the car at average speeds on smooth roads must, therefore, be just that much higher. For instance, it is our observation that a 3¼ to 1 gear ratio will give a noticeably lower fuel consumption at ordinary conditions of steady driving than a 4¼ to 1 gear

Digitized by Google

ratio. As an instance of this, we have found that to pull a certain 3½ by 5-in. six-cylinder car of 4000 lb. total weight at 20 miles per hr., which is 910 r.p.m. of its engine on high gear, requires 4.2 hp. or 12.6 lb. per sq. in. mean effective pressure with the clutch in and the throttle at the position corresponding to a speed of 20 miles per hr. on a smooth road, and 2.75 hp. or 8.2 lb. per sq. in. with the clutch in and the throttle wide open. Note the percentage of loss!

High gear reductions are used today mainly to ensure flexibility in operation of the car at low speeds. One of the reasons why this low-gear ratio is necessary is that the torque of many of our engines today falls off badly below 600 and sometimes 1000 r.p.m. I am quite sure that if our engines were designed so that the torque carried down to lower speeds, the car would be found to operate as nicely with a considerably higher gear ratio, and the fuel economy would be considerably improved.

It is today common knowledge that the difficulties encountered with carburetion are almost entirely due to the fact that parts of our fuels will not and cannot take the vapor form in the intake manifold, and their carriage and distribution to the cylinders has to be accomplished by the friction of the air carrying along the liquid drops and a film of liquid over the manifold walls. The distribution of this liquid part of the fuel is erratic and uncertain, and it is common practice to adjust the carbureter so that enough fuel is fed to furnish a combustible mixture from the elements which do vaporize in the manifold. This results in an irregular excess feed of heavy elements into the cylinders, which gives a heavy carbon deposit, fouls spark-plugs, destroys the valve seats, and, escaping past the pistons, interferes with the lubrication of the engine.

I cannot see that the use of a non-adjustable carbureter would help this condition in any way. When the engine is cold, the driver must have a rich mixture or the engine will not run at all, and whether the adjustment is on the carbureter or on the dash the average driver will not change his adjustment to follow the temperature. This adjustment dare not be accomplished automatically because of the great variation in the volatility of the fuels which are sold in different parts of the country and even in the same town; for an automatic temperature regulation which would be right for a heavy fuel would make it almost impossible to operate the engine on a lighter one.

Digitized by Google

I, therefore, believe that for the next 5 yr. it would be of great value to have a standard lighter grade of fuel which could be used on engines with an unheated intake manifold, or in the winter time on manifolds that are water-jacketed or receive small quantities of exhaust heat. Engines which have properly proportioned "hot spots" could use the heavier fuels, as could engines which, though not so well equipped, operate under heavy loads so that their working temperature is kept up to a point of efficient operation.

F. E. WATTS:—The most important issue raised by Dr. Dickinson's interesting paper is the question of a joint policy as to fuel development and sale to be formulated by the automotive and oil industries. While it is probable that we can build satisfactory engines to use almost any fuel if we know far enough in advance what that fuel is going to be, we are at present working practically in the dark and guessing at the future. The spectacle of the great automotive industries drifting along without making any systematic effort to settle the fuel question, upon which their continued prosperity depends, is appalling. A joint committee should be appointed. A survey should be made of the world's fuel resources. A list of available fuels, their amounts and their properties, should be published 3 and preferably 5 yr. ahead of production. If this is done we can develop engines to use these fuels economically. All other phases of the question become relatively unimportant details compared with this.

DR. DICKINSON:—The point which Mr. Mock makes regarding the effect of gear ratio on fuel economy is of particular interest. This suggestion indicates that the inherent advantages of lower friction losses due to smaller size in the later engine designs of small size and relatively high-gear ratio may be more than counterbalanced by the increased pumping losses attending the increase in gear ratio. This illustrates the importance of a *complete* analysis of each of the elements in power loss.

It is quite true that the best fuel adjustment cannot be obtained with a non-adjustable carbureter design under varying conditions of temperature, volatility and viscosity of fuel; nevertheless, from a practical point of view it is almost certain that the inherent difficulties in these directions could be overcome sufficiently to permit satisfactory carbureter performance under all reasonable conditions without adjustment other than for idling, and

Digitized by Google

with a much lower fuel consumption than is now secured in practice. While this may not be true for all existing carbureter designs, I believe that only minor modifications would be required to accomplish the desired result with any of the successful models. For instance, some effective means of temporarily securing much more complete atomization without increasing the mixture ratio when warming up an engine would produce, with a relatively small loss in volumetric efficiency, the same result as is commony produced by excessively enriching the mixture.

Mr. Mock's suggestion that a special lighter grade of gasoline be supplied for use in less modern equipment would offer an ideal solution from the point of view of the designer and user of motor vehicles. There are, however, very serious objections to such a plan, among which are the fact that to market a given quantity of such special gasoline would reduce the total available supply, and the demand for the special gasoline, if available, even at a very much increased price would be very large because of the added comfort and convenience in its use. The net result would be a marked reduction in available fuel, unless there is a corresponding increase in the equipment which will use the heavier grades of fuel.

Digitized by Google

MEXICO AS A SOURCE OF PETROLEUM AND ITS PRODUCTS

By R. De Golyer[1]

MEXICO achieved second place among the petroleum-producing nations of the world in 1918. This position will not soon be relinquished, judging from the study made by the author of the two general regions from which petroleum has thus far come.

The Petroleum Commission of the Mexican Government has issued statistics covering the production by years since the industry started. It is confidently hoped that future production will continue, as indicated, to stop the gap, constantly increasing and critical, between production and consumption in the United States. A section of the paper is devoted to the export trade, especially with this country, which furnishes the nearest great market.

Mexico, with its production of approximately 67,000,000 bbl. in 1918, apparently achieved second place among the petroleum-producing nations of the world. The United States, with a marked production of some 345,000,000 bbl., was secure in first place, but it is certain that revolution-ridden Russia could not have produced enough of its normal 60,000,000 to 70,000,000 bbl. to enable it to retain second place.

This position, now gained by Mexico, will not soon be relinquished. The potential production since 1911, the year in which Mexico became an exporter of petroleum, has been far in excess of the actual production, which in the past few years has been limited by the serious tank steamer shortage resulting from the great war. With the ending of the war, the tankers are being rapidly released and many of them are going into the Mexican trade. Production for the present year is likely to be greatly in excess of that of 1918.

There are two general regions in Mexico from which petroleum has been produced—the highly important Tampico-Tuxpam region and the less explored Tebuantepec-Tabasco region. The Tampico-Tuxpam region, which includes the section of the Gulf coastal plain adjoining the ports of Tampico and Tuxpam, is the region

[1]Consulting geologist, New York City.

Digitized by Google

from which practically the entire commercial production of Mexico comes at the present time.

The fields of the Tampico-Tuxpam region are divided generally into two groups—those of the Panuco River valley region and those of the southern or Tuxpam region. The fields of the Panuco River valley region, including the Panuco, Ebano-Chijol, and Topila pools, produce heavy viscous petroleum of 10 to 13 deg. Baumé gravity which are used principally in their crude state as fuel oils. The fields of the Tuxpam zone, including Potrero del Llano, Casiano-Tepetate, Cerro Azul, Los Naranjos, Alamo, and Furbero pools, produce lighter petroleums of 19 to 22 deg. Baumé gravity which are the Mexican petroleums used generally for refining purposes.

Approximately 69 per cent of the petroleum produced in Mexico in 1917, the last year for which detailed statistics are as yet available, was of this grade, and 31 per cent was of the heavier Panuco grade. The proportion of the lighter crude was probably even greater in the production of the past year. Of the 1917 Mexican petroleum production, some 77.6 per cent was exported. Exports for the past year show an even greater percentage and will increase as the Mexican production increases. Of the petroleum remaining in the country during 1917, the equivalent of 5.2 per cent of the total production represents fuel consumed by the Mexican railways and 1.5 per cent represents petroleum consumed principally as fuel in the industry itself. The remaining 15.5 per cent of the total production includes petroleum and products consumed in Mexico, refining losses, increase in storage, if any, etc.

Export Trade with the United States

The United States is the greatest single market for Mexican petroleum. In spite of limited transportation facilities during 1917 because of tanker shortage, the United States took petroleum and products from Mexico equal to 65.9 per cent of its entire production. Other nations took 11.7 per cent. The imports of crude petroleum, distillates, and various refined products from Mexico to the United States during that year were equal to more than 10 per cent of the entire production of the United States in its banner year, the one just past.

The benefits resulting from this condition are reciprocal. The United States profits by getting the pe-

Digitized by Google

troleum, and Mexico, by the nearness of a great market where, as a result of experience acquired from the utilization of its own immense petroleum supplies, American industries are accustomed to the use of petroleum and its products to an extent not equaled in any other country of the world.

It has been noted that the potential production of Mexico is far in excess of its actual production. It is estimated that the total capacity of wells already completed in Mexico is more than 1,000,000 bbl. per day. In other words, if the petroleum could be taken care of, so that all the wells could be opened at once, the rate of production would be some eight to ten times the actual present rate. This potential production is slightly greater than the present actual production of the United States. The comparison is likely to mislead, however, unless it is remembered that the production of the United States is an actual proved production and can be maintained for some time by drilling up proved areas, whereas to maintain the actual production of Mexico for a year at its potential capacity would undoubtedly require the discovery of new fields.

We have been so impressed by the unprecedented size of some of the Mexican gushers and by their continued production of large quantities of petroleum over long periods of time without any appreciable decline in amount of petroleum produced daily or in field pressures that we have perhaps overestimated the total amount of petroleum to be secured from any single pool. The explanation of the great gushers seems to lie in the very great porosity of the rock in which the petroleum occurs. It collects in a network of caves and channels previously dissolved out of a bed of very thick limestone by the action of water. This condition allows the petroleum to move about very freely while still underground. Furthermore, the petroleum generally lies over water under an artesian head and as a consequence the field pressure is largely hydrostatic rather than gas pressure, which in most oil fields is the expulsive force causing the oil to flow. Effectively, the result of these conditions seems to be that in Mexico there are deposits of petroleum which can be exhausted with a single well, whereas a deposit of the same size under different conditions of occurrence would require hundreds if not thousands of wells to exhaust it. For comparative purposes it might be noted that there are two wells in Mexico, Potrero del Llano

Digitized by Google

No. 4 and Juan Casiano No. 7, either of which has produced more petroleum than any single field along the Gulf Coast of the United States, while the production of the biggest fields of the Gulf Coast has come from hundreds, if not thousands, of wells, in each instance. The gusher condition in Mexico seems to indicate ease in exploiting rather than such abnormally large pools as have been inferred from the great size of the gushers encountered.

Development Since 1910

Until 1910 both the actual and the potential production of Mexico were almost insignificant; in fact, not great enough to supply the domestic trade of Mexico itself. Petroleum was imported from the United States and refined at the Minatitlan plant of the Mexican Eagle Oil Co. and the Tampico plant of the Waters-Pierce Oil Co. Small amounts of petroleum were produced at Furbero and in the Isthmus of Tehuantepec and refined by the Mexican Eagle Oil Co. at Minatitlan. A small amount of very heavy petroleum produced at Ebano by the Mexican Petroleum Co. was being topped in a small field plant. The distillate was sent to the Tampico refinery for further treatment and the residue made into asphalt or used as fuel on the Mexican railways. The highly important Dos Bocas and Casiano fields had been discovered, but Dos Bocas had been lost by fire and the discovery wells in the Casiano field had fallen off in production until there was some doubt whether they would be able to supply enough petroleum to run the pipe line then under construction to Tampico.

During 1910, however, the Potrero and Tanhuijo fields were discovered and Potrero No. 4, which has since produced more than 100,000,000 bbl. of petroleum, was brought in. Juan Casiano No. 7, with a record second only to that of Potrero No. 4, was completed and the discovery well in the Panuco field was brought in.

The potential production of Mexico thus became so great that she had petroleum far in excess of her own requirements—far in excess of the capacity of transportation systems reaching tidewater and thus making the petroleum available for export. This condition has been permanent since that time, so that today the developed production of Mexico is greater than can be carried to tidewater by her rapidly developing pipe-line systems or river-barging equipment. Even if the entire present

Digitized by Google

production could be got to tidewater, it is doubtful whether there are enough ships available to distribute it to the world markets or whether the markets could immediately absorb it. Great fleets of tank steamers to carry Mexican petroleum have been built by the Eagle Transport Co., Ltd. (British), and the Petroleum Transport Co. (American), controlled by the Pearson and Doheny interests respectively, the foremost producers of Mexican petroleum.

The members of this Society are doubtless particularly interested in estimates of the future petroleum supply which can be expected to come from Mexico. The future of supply rather than the past is of greater interest to prospective consumers.

Estimating petroleum reserves is under the best of conditions a somewhat uncertain business. There was the old method of calculating the oil content of a field or property from the thickness and porosity of the oil-bearing rock. The estimate so secured was modified by a safety factor of 20 to 50 per cent to cover petroleum which could not be mined, and on the resultant guess was based the best estimate as to petroleum reserves. The correctness of such a form of estimate depends largely upon a felicitous selection of the safety factor.

We do a little better now perhaps by estimating the probable production of wells to be drilled or the reserve remaining in wells already producing by comparison with the production of average wells in the same or in similar fields. Such a study involves the construction of production curves, the various points on a curve being determined by plotting the amounts produced from a single well or an average well as the ordinates, with the fixed units of time in which produced, arranged consecutively, as the abscissas. Data for the construction of such a graph, to be of any value, must show the changes in the amount of unrestricted production of a given well or average well during various units of time.

We can make estimates of reserves in the Mexican fields by neither method. We have no data as to thickness or porosity of the petroleum-producing formations and consequently cannot use the volumetric method. The bulk of petroleum from Mexico has come from wells of such size that only the production from a restricted flow could be utilized. Production curves constructed on such artificially restricted data as are available under these conditions would be almost valueless. Nevertheless, we

Digitized by Google

can make a rough guess as to the fields already producing in Mexico. It seems fair to assume, on the basis of past performances, that the fields already producing in Mexico indicate what one might call a blocked-out reserve of from half billion to a billion barrels of crude petroleum.

Geologic conditions indicate that other petroleum fields of greater importance than those now known will yet be discovered in Mexico. So far as exploratory drilling is concerned, the petroleum regions have been but scratched. Not more than 1000 wells have been drilled in all of Mexico since the earliest attempt to discover petroleum. Included in this are a great number of wells drilled for exploitation purposes in fields already discovered, and a number of wells drilled in Tabasco, the Isthmus of Tehuantepec region and various outlying regions.

Remarkably few wells are being drilled in Mexico when one considers the amount of petroleum produced. According to official statistics, seventy-nine wells were drilled in 1917, and of them forty-three were productive, with an estimated initial output of 235,027 bbl., and thirty-six were dry holes and abandoned. Bardone of the *Oil and Gas Journal*, estimates that twenty-three wells were completed in the first half of 1918, twelve of them being producers, with an estimated initial production of 350,000 bbl. For comparative purposes, it might be noted that 1117 wells were completed in Kansas and Oklahoma in the single month of July, 1918. These successful wells have been in proved pools with the single exception of Molina No. 2, which was drilled during the latter part of 1917 and which was the discovery well of a new field.

The greatest needs of the Mexican petroleum industry at the present time are some relief from the continually increasing taxes, which are apparently designed to be confiscatory, and some degree of safety in the petroleum-producing regions in order that much needed drilling of an exploratory nature may be carried on.

The use of Mexican crude petroleum in internal-combustion engines has not yet passed beyond the experimental stage, but more and more crude petroleum is being refined for its light oil products and this forms an increasingly important addition to the world's supply of engine fuel. The Mexican Eagle Oil Co., Ltd., has refineries at Minatitlan and Tampico and a topping plant at Tuxpam. The Waters-Pierce Oil Co. has refineries at Vera Cruz and Tampico. The Standard Oil Co. of New

Digitized by Google

Jersey has a refinery at Tampico. The Texas Co. has topping plants at Port Lobos and Tampico. The Doheny interests have a topping plant at Tampico and an asphalt plant at Ebano. The Atlantic Refining Co. has a topping plant at Port Lobos.

Only the 19 to 20 deg. Baumé petroleums of the Tuxpam region are refined in quantity in Mexico. All of the refineries and topping plants run it except the Tampico plant of the Texas Co., which tops some Panuco crude, the Ebano asphalt plant which runs Ebano crude, and the Tampico refinery of the Waters-Pierce Oil Co., which runs a very small amount of Topilo crude besides much greater amounts of Tepetate-Casiano, Naranjos and Potrero crudes.

Panuco crude is used mostly for fuel purposes. It is so viscous that after the very small light oil fraction has been removed, the residue can be handled only with the greatest difficulty and by specially designed equipment. Panuco crude is imported to the United States and, after being mixed with Gulf Coast crudes, is successfully refined. One American refinery is reported to crack Panuco crude, thus securing 12 to 16 per cent of gasoline or engine fuel.

The greatest possibilities for future extended uses of Mexican petroleum seem to lie either in the further perfection and more widespread development of internal-combustion engines using very heavy oils as fuel, or in an improvement of refining methods by which heavy oils can be more easily converted into lighter oil. It is likely that both methods will be utilized. In the past several years the continued development and widespread use of internal-combustion engines has created such a demand for fuel that it has been supplied only by great efforts on the part of the producer and refiner of petroleum. Fortunately for the petroleum industry, this demand has set the mark and the internal-combustion engine has not waited to be assured of a source of supply for a fixed number of years in advance.

As to the great advantage of the use of Mexican petroleum in internal-combustion engines over its use as fuel for boiler installations there can be no doubt. In this connection, one can hardly do better than quote from a recent paper by Lord Cowdray, head of the Mexican Eagle Oil Co., Ltd., and affiliated organizations:

Digitized by Google

It should be stated that Mexican oil, especially refined for use in Diesel engines, is now available for motorships. It is possible that the subject of internal-combustion engines for ships has been discussed with an excess of optimism and led to expectations that have not yet been fully realized, but the most conservative observer cannot fail to be impressed by the solid progress already made in this direction, and the utility of the oil engine for moderate-sized vessels seems to be soundly established. The primary advantage is disclosed in the following figures, giving approximately the comparative consumption by main and auxiliary machinery for various types of marine propulsion.

	Lb. of fuel per hp.-hr.
Steam engine, coal-fired	1.60
Steam turbine, coal-fired	1.30
Steam engine, oil-fired	1.00
Steam turbine, oil-fired	0.82
Oil engines	0.50

It will be seen that the oil engine can claim the lowest consumption; the vessel's radius is considerably increased. These are factors which will inevitably insure a great future for motorships, and the provision of fuel supplies on an ample scale will accelerate their progress.

Year	Bbl.	Metric tons
1901	10,345	1,544
1902	40,200	6,000
1903	75,375	11,250
1904	125,625	18,750
1905	251,250	37,500
1906	502,500	75,000
1907	1,005,000	150,000
1908	3,932,900	587,000
1909	2,713,500	405,000
1910	3,634,080	542,400
1911	12,552,798	1,873,552
1912	16,558,215	2,471,375
1913	25,696,291	3,835,267
1914	26,235,403	3,915,732
1915	32,910,508	4,912,016
1916	40,545,712	6,059,589
1917	55,292,770	8,264,266
1918 (estimated)	67,000,000	10,000,000
Total	289,082,472	43,166,241

Statistics covering the production of petroleum by years since the beginning of the industry have recently

Digitized by Google

been made public by the Petroleum Commission of the Mexican Government. They show the past history of Mexican petroleum and indicate prospects for future increases in production better than can be done in any other manner.

It is confidently hoped that the future production of the Mexican fields will bear out fully the continued increase in amount indicated by the foregoing figures and that it will stop the constantly increasing and extremely critical gap between production and consumption in the United States.

FIXED RADIAL CYLINDER ENGINES

By John W. Smith[1]

DURING the first two years of the war the author conducted in England experimental work for the British Government on the engine he describes. After brief mention of V-type water-cooled engines and the general situation as regards revolving air-cooled and radial water-cooled types, the discussion is narrowed to two distinct designs of fixed radial air-cooled engine, both of which have been tried out and seen some service.

The fundamentals in which fixed radial air-cooled engines give promise of excelling are weight of powerplant per horsepower, the fuselage mounting and space required being duly considered; reliability and durability; fuel and oil consumed per horsepower-hour; streamline mounting, with armor, if desired; quick detachability of powerplant; accessibility, and freedom from certain inherent difficulties peculiar to water-cooled engines. As these several matters are discussed many points are brought out to show the details of modern construction, shop practice under certain difficulties, the new roller bearing, a connecting-rod layout, British figures on fuel consumption, mounting advantages and disadvantages, and cooling construction problems.

It is assumed that an engine possessing the inherent advantages claimed will be further perfected and come into wide use.

This article will treat chiefly of fundamental characteristics, the sum of which is a measure of the real

[1]Designer of fixed radial airplane engines, Philadelphia, Pa.

Digitized by Google

value of an airplane engine. Detail comparison will not be attempted.

With the experience gained from the war, we find Great Britain keenly interested in the fixed radial cylinder, air-cooled engine. She has taken the lead in the development of this type, has spared no expense, and has demonstrated its merits for aviation to her own satisfaction. It is, I believe, only a question of time before this engine will be sufficiently well known to cause America to turn her attention to it.

The V-type water-cooled engine has been fully developed and the Liberty engine represents, perhaps, the last word in the development of this type. It is my belief that the future has little in store that will greatly improve it. The V-engine was developed largely by the automobile industry and is in effect, and quite naturally, built largely along automobile lines. It is, however, lacking in certain desirable characteristics, which if they can be realized mean a much improved airplane powerplant.

The revolving air-cooled engine, like the V-type water-cooled type, has been fully developed, and most if not all of its possibilities have been realized, while its disadvantages are well understood. At present the United States and Great Britain are both ready to discontinue the use of the rotating air-cooled engine because of certain inherent disadvantages; therefore, neither this type nor the radial water-cooled, will be discussed at length. It is my belief that while the radial water-cooled engine may, when properly developed, be an improvement over the V-type water-cooled unit, it will still be much heavier than the radial air-cooled type.

At the present time there are two distinct designs of fixed radial air-cooled engine. Both have been tried out by the British Government and have seen some service.

I was in England the first two years of the present war, conducting experiments for the British Government on a fixed radial air-cooled engine. From the information gained as a result of my own experiments, together with the development work of others, I am convinced that the fixed radial air-cooled engine will excel in each of the following fundamentals:

(1) Weight of powerplant per horsepower, the fuselage mounting and space required being duly considered
(2) Reliability and durability
(3) Fuel and oil consumed per horsepower-hour

Digitized by Google

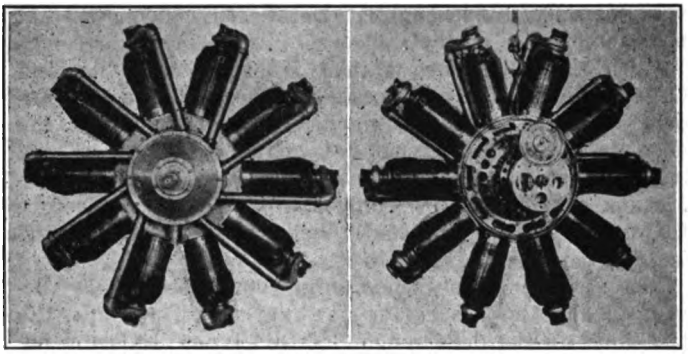


FIG. 1—FRONT AND REAR VIEWS OF TEN-CYLINDER 200-HP. SMITH-FIXED RADIAL ENGINE

(4) Streamline mounting, with armor, if desired
(5) Quick detachability of powerplant, and accessibility
(6) Freedom from certain inherent difficulties peculiar to water-cooled engines

WEIGHT OF POWERPLANT

There is a great deal of confusion about comparing weights of engines. It is customary to refer to the weight of the water-cooled engine by giving the weight dry, which omits the weight of the water and radiator. A fair comparison of weight should include the entire powerplant mounted in the fuselage with sufficient fuel and oil for some hours of operation. The water-cooled engine requires more fuselage space and in addition elaborate sheet-metal casing and exhaust piping to complete the powerplant. The mounting of a nine or ten-cylinder radial air-cooled engine shows a saving in weight over the water-cooled, when all elements are included. If the entire powerplant is included in giving the weight of the water-cooled engine, it will be found that the lightest water-cooled type, which is probably the Liberty engine, will weigh over 2.7 lb. per hp. for the 400-hp. size as installed in the airplane. Smaller water-cooled engines will weigh 8½ lb. or more per hp. The English Rolls-Royce 300-hp. engine weighs 3½ lb. per hp.; weights made up as follows: Engine 860 lb., radiator and water 167 lb., exhaust pipes 33 lb.; a total of 1050 lb., or 3½ lb. per hp.

Fig. 1 shows a 200-hp., ten-cylinder radial air-cooled engine of 4 17/32-in. bore and 6¼-in. stroke, which weighs less than 1.8 lb. per b.hp., installed. A 400-hp. ten-

Digitized by Google

cylinder engine, which is illustrated in Fig. 2, has 5½-in. bore and 6½-in. stroke, and an estimated weight of 1.3 lb. per b.hp. The nine-cylinder engine, Fig. 3, has 5½-in. bore and 6½-in. stroke, and is said to develop 310 hp. and weigh 640 lb., or 2.06 lb. per b.hp.

It will thus be seen that the fixed radial-type engine has a weight advantage of fully 0.6 lb. per hp. over the water-cooled type, and it can be designed to have a much greater advantage.

Reliability, Durability and Balancing

The construction of the fixed radial engine makes for reliability, because of its simplicity and compact design. The English have developed the roller bearing to a point where it is practically infallible for crankshaft and connecting-rod applications. This is applied to the nine-cylinder engine, as well as to the engine shown in Fig. 3. A simple oiling system is adaptable to an all roller

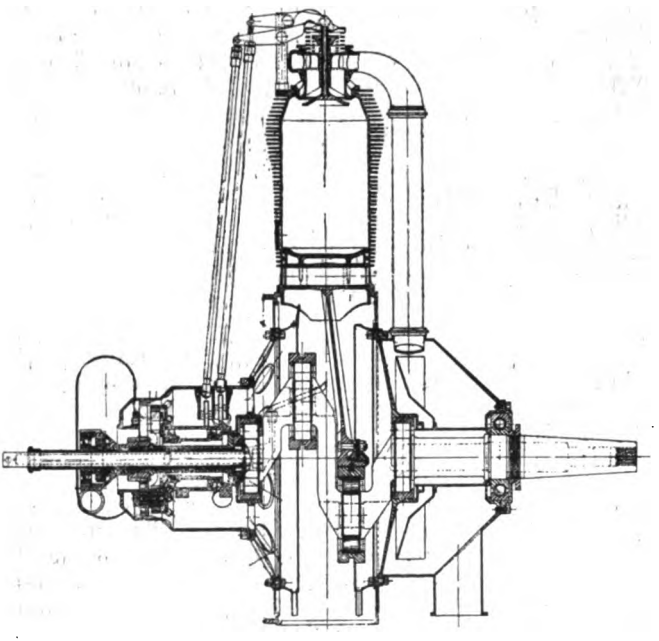


Fig. 2—Lateral Section of 400-Hp. Smith Fixed Radial Engine

Digitized by Google

bearing, fixed radial engine. The ten-cylinder engine shown in Fig. 2 has an oiling system that does not depend upon a fixed pressure and in which the oil is sprayed from one point only. The circulating and fresh supply of oil is pumped through the hollow crankshaft and is thrown off by centrifugal force onto all the cylinders in a uniform manner, the bottom cylinder getting the same supply as those at the top. This oiling system works out well in practice.

The connecting-rod layout used in the same ten-cylinder radial engine is extremely simple and has proved to be one of the most reliable arrangements ever used on any type of engine. An engine equipped with the same rod design was flown over 8000 miles in a British military airplane, which is equivalent to running the engine for over 100 hr. without any adjustment of the rods. Engineers who examined the rods and bearings estimated that at least 400 hr. service might be expected. The connecting-rod design used in the nine-cylinder engine, Fig. 3, has been used extensively in the revolving-cylinder type engine and found to be satisfactory but is limited to the single-throw crank, which does not give the mechanical balance found in the ten-cylinder engine shown in Fig. 2. To produce a perfectly balanced fixed radial engine, the axes of all cylinders should be in the same plane, and the pistons connected to opposed two-throw cranks.

In this connection it is worth noting that the nine-cylinder engine, with single-throw crank, must be counter-balanced by weights, as shown in Fig. 3. For this reason it is evident that considerable weight can be saved by resorting to the double-throw crank construction shown in Fig. 2.

The foregoing are factors affecting reliability and durability which cannot be said to apply, at least in the same degree, to other types, when due regard is given to light construction.

Fuel and Oil Consumption

There is every r[illegible] believe that the fuel consumption of the fixed r[illegible] should be at least as good as that of the o[illegible] V-engine, since the mean effective pressure [illegible] can, with proper design, admitting of ad[illegible] piston cooling in combustion with re[illegible] compression, be made to equal that in [illegible] practice, while mean-

Digitized by Google

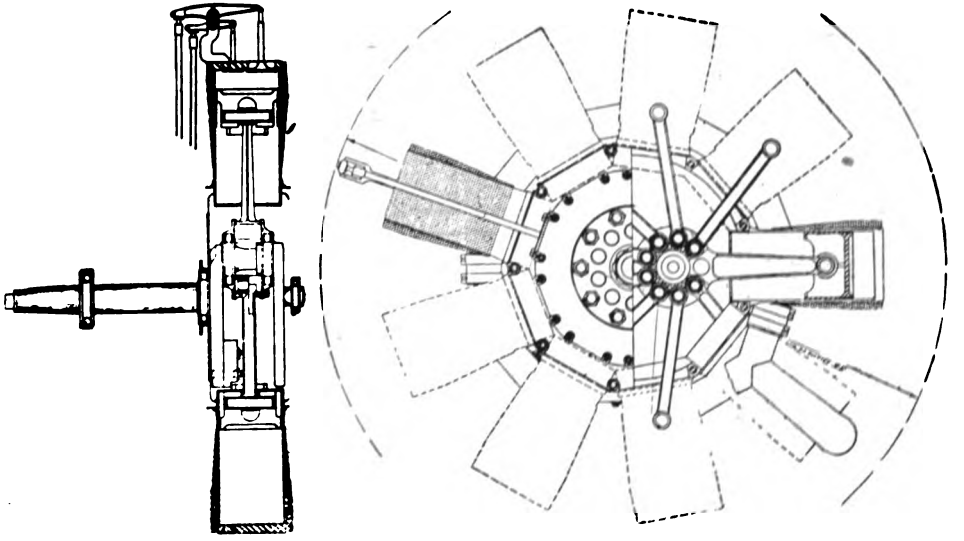


FIG. 3—LATERAL SECTION AND ELEVATION PARTLY IN SECTION OF NINE-CYLINDER ENGINE OF BRITISH MANUFACTURE WITH SOME DETAILS OMITTED

Digitized by Google

ing friction is less with roller-type bearings than with plain bearings.

Official British reports on the ten-cylinder engine, Fig. 2, have credited it with a fuel consumption of less than 0.50 lb. per b.hp.-hr., and oil consumption of less than 0.02 lb. per b.hp.-hr. I understand that the nine-cylinder engine uses less than 0.45 lb. of fuel per b.hp.-hr. This consumption compares favorably with that of the best water-cooled engines. There is no question about low oil consumption for the fixed radial engine, because of the compact disposition of parts, and the fact that only roller-bearings are employed.

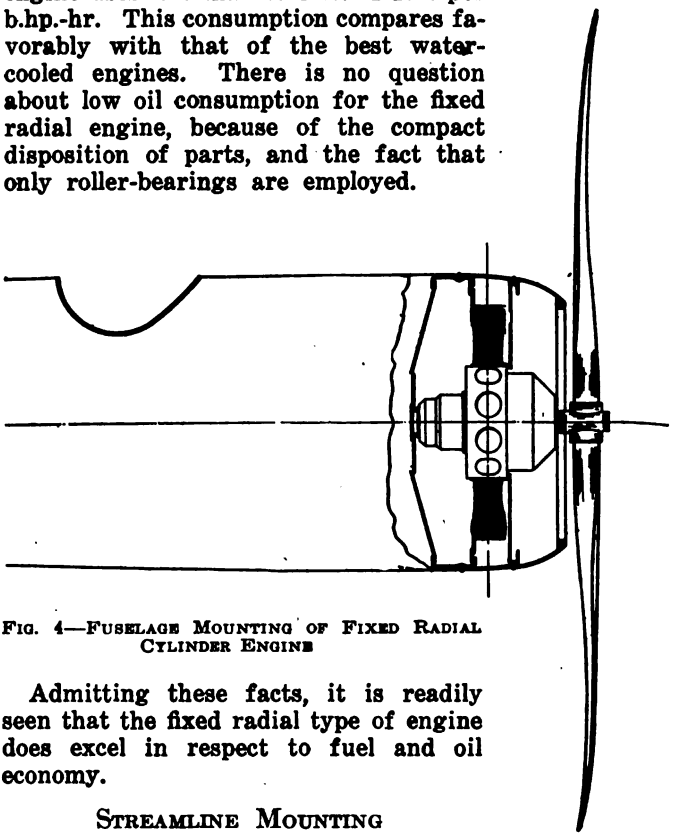


FIG. 4—FUSELAGE MOUNTING OF FIXED RADIAL CYLINDER ENGINE

Admitting these facts, it is readily seen that the fixed radial type of engine does excel in respect to fuel and oil economy.

STREAMLINE MOUNTING

In the course of considerable development work on both wood and steel propellers, with the object of increasing their efficiency, I have found that near its center the work done by the propeller is negative; that is, the work done on the air in this region is greater than the work resulting in thrust. This is due largely to the relatively poor aerofoil section required for structural reasons. The difference of pressure of the air before

Digitized by Google

and after it is acted upon by the propeller causes an eddy near the center of the propeller, and this tends to increase the negative work further. It is, therefore, important to prevent circulation of this air near the center, and this can be done by a proper propeller cap, as illustrated in Fig. 4 for fuselage mounting, or Fig. 5 for wing mounting. In the case of a well-designed propeller now being extensively used, the thrust resulting from that part of the propeller with a 20-in. radius was found to be less than 5 per cent of the total available at the normal speed, while the negative work done by the same part is such as to result in a net loss, which

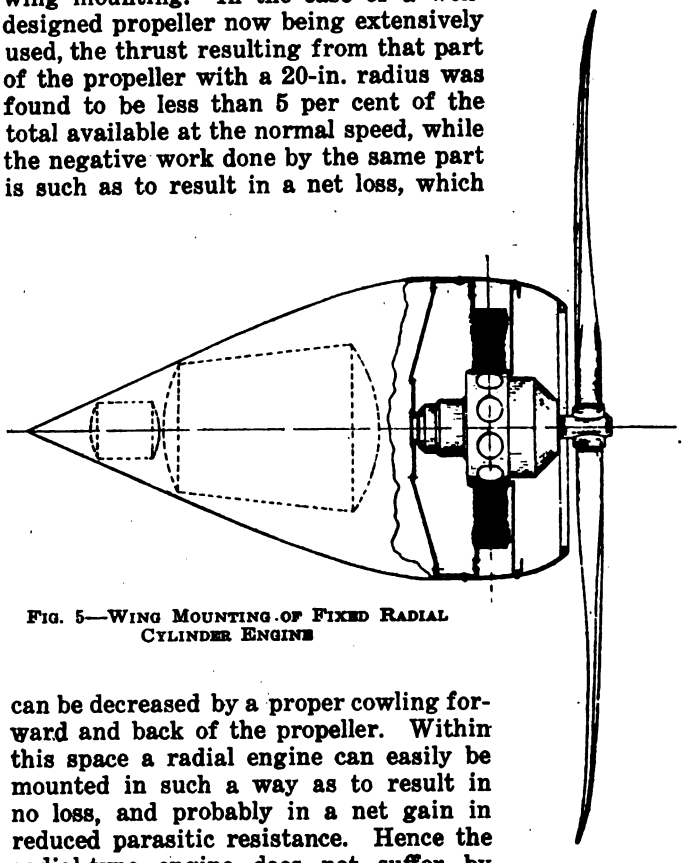


FIG. 5—WING MOUNTING OF FIXED RADIAL CYLINDER ENGINE

can be decreased by a proper cowling forward and back of the propeller. Within this space a radial engine can easily be mounted in such a way as to result in no loss, and probably in a net gain in reduced parasitic resistance. Hence the radial-type engine does not suffer by comparison with other types in this respect. In fact, the water-cooled powerplant, with radiator and fuel tank, cannot be as efficiently streamlined as can the ten-cylinder fixed radial type. Fig. 5 shows wing mounting for a 400-hp. ten-cylinder fixed radial powerplant with ample space for fuel and oil tank.

It is very interesting to compare the V-type engine and

Digitized by Google

the fixed radial engine, both mounted in the fuselage. The water-cooled engine shows an extremely complicated mounting in comparison with the fixed radial. The water-cooled engine may be termed the fore-and-aft type, and the fuselage is practically built around the engine, of which it virtually becomes a part. This results in relative inaccessibility. Fig. 4 shows the fixed radial engine properly installed in a streamline mounting. By removing two bolts the front portion of the casing can be removed, exposing the engine for inspection. Any necessary adjustments can readily be made, and cylinders and pistons easily removed and valves ground, without interfering with the installation as a whole. The entire powerplant can be removed, if desired, by releasing four bolts and disconnecting the fuel and oil pipes, there being no troublesome water connections to interfere.

The steel shell in which the engine is mounted can also be made of armor-plate, thus protecting it without adding excessive weight. These surely are points of superiority not to be overlooked.

Cooling

It is admitted that the cooling of a fixed radial-type engine presents some serious problems. These are, however, by no means insurmountable, and most, if not all of them, are believed to have been solved in the ten-cylinder fixed radial engine shown in Fig. 2, which is internally cooled. The cooling air is admitted to the crankcase, and forced up against the pistons. The exhaust-valves are also cooled by contact with the cold entering charge which passes through them. This internal cooling system makes it possible to mount the engine in an enclosed steel shell which is simply a continuation of the fuselage. The nine-cylinder engine referred to has no facilities for internal cooling. It is, therefore, not installed inside a streamline shell. To cool the nine-cylinder engine properly at least one-third of the cylinders are placed in the slip-stream of the propeller. This necessitates small exhaust pipes to prevent hot oil from reaching the pilot.

The disadvantages of a water-cooled powerplant for both military and non-military uses are so obvious that it is not necessary to compare in detail the advantages of the fixed radial air-cooled type, further than to suggest that it is easier to control the cooling air on the ten-cylinder powerplant shown in Fig. 2 than it is to prevent

Digitized by Google

the water from freezing in the case of a water-cooled powerplant, and to point out that it is easier to provide a supply of cooling air to an air-cooled design than it is to maintain a non-leaking water system.

Conclusion

If, then, the fixed radial air-cooled powerplant for aeronautic use possesses so many advantages, it is natural to inquire why it has not seen wider application. The reason for this is quite obvious to those who are familiar with conditions that have existed during the war. The water-cooled V-type engine was a known factor. While the perfection of a water-cooled engine suitable for quantity production presented many problems, as those who were instrumental in developing the Liberty engine will readily admit, it was quite properly felt that these were easier and more certain of rapid and definite solution than were the problems involved in the fixed radial air-cooled type. These circumstances, and the fact that this country was faced with a serious military problem which required prompt and certain solution, made it most advisable to follow the course which was adopted. However, now that the war is over, and there is more time for normal development, is it not fair to assume that an engine possessing the inherent advantages pointed out in this paper will be perfected and see wide use? It is my belief that this question will be answered in the affirmative.

Digitized by Google

PROBLEMS OF THE NAVAL AIRCRAFT FACTORY DURING THE WAR

By Commander F. G. Coburn,[1] U. S. N.

THE Navy Department established the Naval Aircraft Factory (*a*) to assure a part, at least, of its aircraft supply; (*b*) to obtain cost data for the Department's guidance in dealing with private manufacturers, and (*c*) to have under its own control a factory capable of producing experimental work. The history of this development is given in some detail, including statistics of size, valuations and output.

The problems discussed include (*a*) layout and expansion, describing the original plant and how idle plants in the industrial world were utilized for the production of parts that were afterward assembled at the factory; (*b*) outside production, outlining the placing with plants of contracts for flying-boat hulls, wings, metal parts, tanks, engine foundations, tail surfaces, etc.; (*c*) personnel, telling how both men and women were trained in a special school; (*d*) engineering, covering built-up wooden parts, research in defects of wood, securing of proper material, organization of inspection, traveling representative, traffic and follow-up forces, etc., to expedite production; and (*e*) production methods, showing that by careful scheduling and subsequent working to schedule time-reduction was secured. For example, hull construction was divided into operations of framing, brace wiring, planking, etc., each of which covered a similar kind of work. Various crews were then organized so that each group of operations could be completed in one day. By this method the time required to build a hull was reduced from 41 to 16 days. This system was followed throughout the plane construction.

The reason for the establishment of the Naval Aircraft Factory was the problem of aircraft supply which faced the Navy Department upon the entrance of the United States into the great world war. It is unnecessary to recite these conditions to the members of this Society. It suffices to say that the army's requirements for large numbers of planes promoted a decided lack of interest in the navy's requirements for comparatively small numbers of machines, and the Navy Department therefore concluded that it was necessary to build

[1]Manager, Naval Aircraft Factory, League Island Navy Yard, Philadelphia, Pa.

Digitized by Google

and put into production an aircraft factory to be owned by the Navy, in order, first, to assure a part, at least, of its aircraft supply; second, to obtain cost data for the Department's guidance in its dealings with private manufacturers; third, to have under its own control a factory capable of producing experimental work.

Appointment of an Investigating Board

The Department directed that a survey of the situation be made early in June, 1917, with a report upon the size, cost, and location of a factory capable of producing 1000 navy school planes, known as Curtiss N-9, per annum, and further to report upon the minimum time in which such a plant could be built, equipped, manned and put into operation. The field for investigation was necessarily limited, as at that time only the Churchill Street plant of the Curtiss Aeroplane company could be considered a manufacturing plant for airplanes. There were a number of other firms producing planes in small quantities or getting ready to produce them in large quantities. But scanty information was therefore available and there was no time to make an exhaustive study that under ordinary peace-time conditions would be expected before embarking on an enterprise of this size. Consequently about the middle of July, 1917, it was reported to the Chief of the Bureau of Construction and Repair, Admiral D. W. Taylor, U. S. N., and to the Secretary of the Navy, that a plant of the required size could be built at the League Island Navy Yard at a cost of approximately $1,000,000 in about 100 days.

On July 27, 1917, the Secretary of the Navy approved the project and directed the Chief of the Bureau of Construction and Repair to proceed with the construction.

Building Contracts Awarded

The contract for the buildings was awarded Aug. 6, 1917, ground actually being broken four days later. Beneficial occupancy of part of the building was obtained about Oct. 1, 1917, ahead of the time promised by the contractor. On Oct. 16, 1917, sixty-seven days after breaking ground, the first power-driven machine was put in operation and the entire building was pronounced complete Nov. 28, 1917.

The engineering data and plans for the planes to be built were received by the factory Oct. 26, 1917, and on March 27, 1918, 228 days after ground was broken and

Digitized by Google

151 days after receipt of the plans, the first machine was given its first flight, which was successful, and on April 2, 1918, this machine and the second one were shipped from the factory en route to England. These two boats were the first of the original manufacturing order, which was completed July 2, 1918, ahead of the time scheduled for its completion.

Some figures obtained as of Sept. 30, 1918, about a month and a half before the armistice was signed, will give an idea of the size of the factory at that time. It has been enlarged beyond the bounds of the original project, as will be described.

Total floor space, sq. ft.	750,000	
Total ground covered including lumber yards, acres	41	
Total number of employes	3,600	
Of which were women	750	
Value of plant, buildings, and equipment		$4,476,000
Supplies in store		1,621,000
Work in process		1,662,000
Total inventory		$7,759,000
Value of output		
(a) 183 Twin-engined flying boats (at approximately $20,000 each)		$3,660,000
(b) 4 Experimental machines, 50 sets twin-engined flying boat spares and a considerable volume of ordinary experimental and repair work		200,000
Total value of output		$3,860,000
Payroll for month of September, 1918		$405,000
Total expended in wages up to Oct. 1, 1918		$2,790,000

The Original Plant

The original plant consisted of a building 400 ft. square containing a balanced plane factory—that is, mill, metal shop, panel shop, covering, varnish and dope rooms, hull shop and final assembly, together with the general offices, toilet and locker rooms, cafeterias and storeroom. In addition there was a four-cell Tiemann dry kiln, a brick building 60 by 100 ft., heated, for the storage of kiln dried lumber, a lumber yard with modern pile bottoms for the accommodation of approximately 3,000,000 ft. of lumber, and a boiler house.

Fig. 1 gives the layout of the entire factory buildings, Nos. 1 and 2, constituting the original project, the block

Digitized by Google

to the south of the main building, No. 5, being the lumber yard. The large building is made up of a section 300 by 400 ft. of the Austin Co. No. 3 building, and a special bay 100 by 400 ft. was added to supply hull building and final assembly space. This extra bay was 100 ft. wide with a clearance under the roof trusses of 51 ft., accommodating a 10-ton, three-motor, overhead traveling electric crane with a 40-ft. hook hoist. The provision of this high, wide, long bay seemed to many to be of doubtful value, but it was intended to meet the requirements of the future, which it seemed certain would be for large planes, and as it happened the factory never went into production on small planes, but was started at once on large planes, making this building and its crane a paying investment from the start.

Layout Assured Flexibility

The allocation of space to the various activities of the plant was a problem which did not at the time admit of

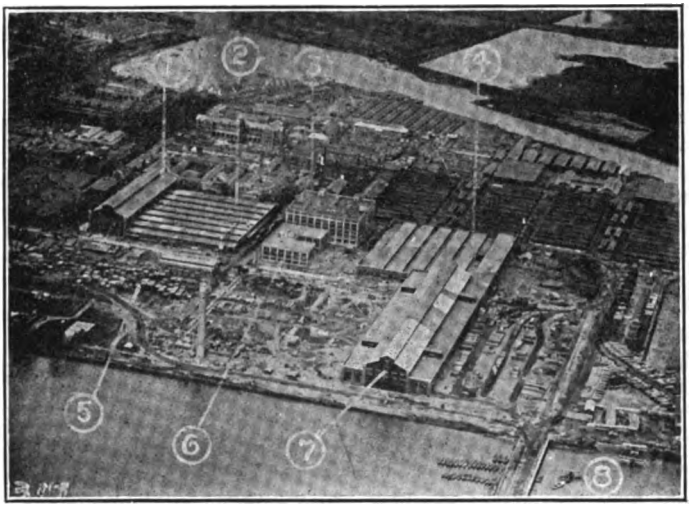


Fig. 1—Airplane View of the Factory, Showing Both the Original and Enlarged Plant

(1) High shop No. 1; original plant
(2) Mill, metal shop, offices, and storeroom of original plant
(3) The storehouse
(4) Panel, pontoon, paint and dope rooms of the enlarged plant
(5) Lumber yard, dry kiln and boiler house
(6) Office building
(7) Assembly shop of the enlarged plant
(8) Hangar

Digitized by Google

definite solution because of lack of definite information as to the types of machine to be built and of information as to the amount of space actually required for known types of machines. The only partitions erected, therefore, were those necessary to meet the following requirements: First, to separate the high bay from the low part of the building, as a fire protection measure; second, to separate the offices, toilet and locker rooms and cafeteria from the factory for fire protection, cleanliness and quiet; third, to enclose the metal shop, and the varnish and dope room, as a matter of fire protection.

The machinery purchased was equipped with individual motors so that no provision for line shafting was necessary and the location of the machines could be changed at pleasure.

Atmospheric Conditions Stabilized

Having noted that a watering-pot was necessary to preserve the necessary humidity in airplane factories and realizing the desirability of standardized and constant atmospheric conditions as to temperature, humidity and ventilation, the Carrier system of heating, humidifying and ventilating was installed. This is the system now being commonly used in cotton mills and was introduced into an airplane factory for the first time. It has automatic temperature and humidity control, the air condition being standardized at that which would provide a good working temperature (65 deg. fahr.) together with a 50 per cent humidity, which would insure that wood dried to 10 per cent moisture content would neither absorb nor give off moisture. It was then insured that small, and particularly thin, wood parts would maintain their size and shape after manufacture and thus facilitate assembling. The system proved most satisfactory.

Probably all plane manufacturers in the aircraft world went through the same distressing times experienced by the Naval Aircraft Factory of having to start work as winter approached in incomplete buildings without light and heat and without those conveniences and articles of equipment that are not appreciated by those who work in established factories.

Problems of Enlargement

In December, 1917, it was decided by the Navy Department to make a very great increase in the aircraft building program to meet the requirements for planes for

Digitized by Google

patrol and convoy work in the North Sea and particularly over the waters contiguous to the coasts of Ireland and France. Although at this time the Naval Aircraft Factory was not yet in production, its original plant was complete, the organization was formed and working, a fair start had been made on the assemblage of a working force, and it gave promise of coming satisfactorily into production. The new program necessitated the provision of additional manufacturing facilities because the army

FIG. 2—CURTISS R6, A PONTOON SEAPLANE; SIMPLY A LAND MACHINE WITH PONTOONS INSTEAD OF WHEELS

was not prepared to release any of the facilities assigned to it by the Aircraft Board.

The first problem was to decide whether or not to construct a balanced factory to supply the needed capacity. After considerable discussion it was decided that the time required for the erection of the building, the assembling of sufficient personnel, etc., was so great as to preclude so doing. It seemed better to utilize idle plants in the industrial world for the production of parts and to erect as an enlargement of the Naval Aircraft Factory an assembling plant to be fed by these sources of parts and minor assemblies.

For this there was provided a building shown in Fig. 1, consisting of two parts: a low building 13 ft. under the roof trusses was provided for panel shop, varnish and dope room, pontoon manufacture, etc., and a bay 100 ft. wide, 51 ft. under the trusses and 680 ft. long for final assembly, flanked on each side by a bay of equal size, 50 ft. wide and 30 ft. under the trusses. The 100-ft. bay was equipped with two 10-ton, three-motor, overhead traveling electric cranes, and the side bays each with a

Digitized by Google

2½-ton small crane. The plan was to manufacture and assemble wings, pontoons and similar parts in the low section, assembling them to jigs and packing them for shipment, the boat hulls to be put through final assembly, packed and shipped from the high bay, while the flanking bays were used for sub-assembling.

Outside Plants Aided Increased Production

As sources for hulls some six yacht building yards were obtained, and for the supply of wings, metal parts,

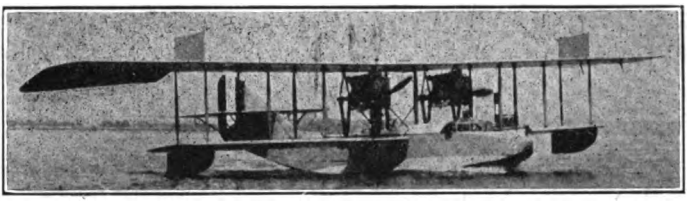


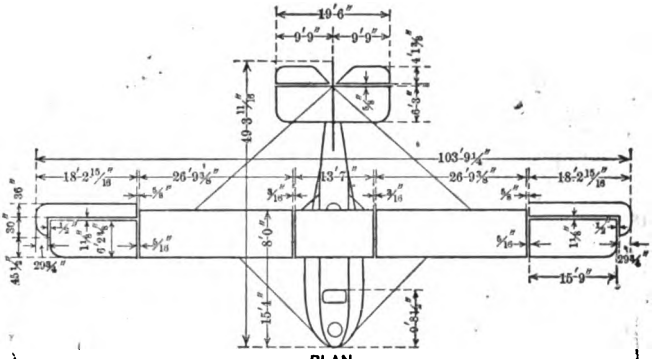
Fig. 3—The First Product of the Naval Aircraft Factory Was a Curtiss H-16 Flying Boat
It Is a Tractor Biplane with Twin Liberty Engines

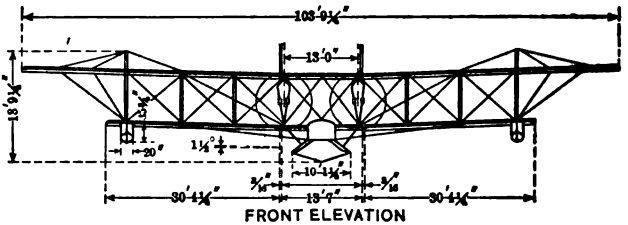
tanks, engine foundation assemblies, tail surfaces, etc., the services of a number of plants were enlisted which might have otherwise stood idle due to the discontinuance of their peace-time business.

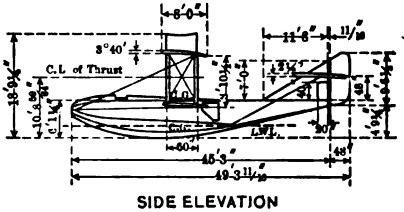
The direction of the entire program was reposed in the central offices of the Naval Aircraft Factory, which necessitated enlarged office space. Therefore, a concrete three-story office building was erected to accommodate the offices and the old office space was put into production. A six-story concrete storehouse, approximately 200 ft. square, was provided to meet the enlarged storage space requirements and the storage room in the original factory was thrown into production space. The dry kiln capacity was doubled, as was also that of the heated storage building and the lumber yards. The success of the Carrier heating and ventilating system in the original plant dictated its installation in the new assembling plant and in the heated lumber storage building.

At this time there was also projected a hangar which was authorized in the spring of 1918 and is now under construction, because of the increase in experimental work, in the development of new models and of new features in old models, necessitating a considerable amount

Digitized by Google







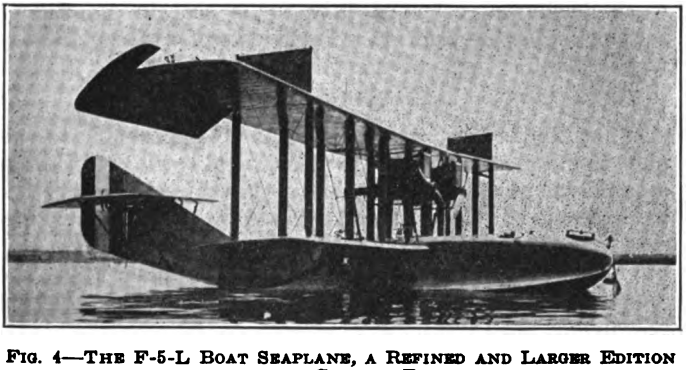


Fig. 4—The F-5-L Boat Seaplane, a Refined and Larger Edition of the Curtiss Boat

It Has a Wing Spread of 104 Ft., a Total Flying Load of Nearly 7 Tons and a 10-Hr. Cruising Radius

Digitized by Google

of alteration on completed planes and test and demonstration flying. The Delaware River affords ample space and climatic conditions are favorable, except for two months in the winter.

This hangar has a door 200 ft. wide and 50 ft. high, and the building itself is 150 ft. deep. In front of this hangar is an apron 100 by 200 ft. made of concrete with a concrete ramp flanked by concrete piers. The concrete is to be colored green to relieve the glare. Provisions are made for the simplification of handling planes on the apron and ramp.

The Philadelphia Navy Yard is on League Island, which comprises approximately 1000 acres, of which over 41 acres are covered by the enlarged plant. A considerable increase in paving, railroad tracks, roadways, etc., was required and was provided for in the allotment, which, including the hangar, amounted to $3,678,000, which was approved for the project by the Secretary of the Navy Jan. 27, 1918.

In the design of the buildings provision was made for sprinklers and the buildings were also supplied liberally with fire buckets, sand boxes and fire extinguishers.

Responsibility for the securing, development and retention of a satisfactory personnel, outside of the executive staff, was placed in an Employment Department, under the direction of an Employment Superintendent. The Employment Superintendent is one of the five main department heads reporting to the manager. The specific functions assigned to the Employment Department originally included employment and training. Later, as the work developed, responsibility for a certain amount of factory follow-up and for all service work of the factory was added.

Training Women

When the factory was starting it was necessary to employ men almost entirely for mechanical work. As soon as a sufficient number of men had been trained to carry the work along, it was considered not only desirable and necessary to use women wherever possible, but also a war duty. The most important training work taken up by the Employment Department had to do with the introduction of women into the factory.

A training school was established for women. Upon employment women were placed in this school and there under close supervision of mechanic instructors, per-

Digitized by Google

formed the same kind of work which they would later be called on to perform in the factory. The work which they do is production work, but it is graded so that a beginning worker has simpler work and is more closely supervised. With these exceptions and the exception of a somewhat shorter working day, the working conditions of this school are made to resemble as nearly as possible the working conditions of the rest of the factory. A sufficient number of girls passed through the school to increase the number of women employes from 218 in June to 895 in November. This was an increase from 9.4 to 24.5 per cent of the entire force.

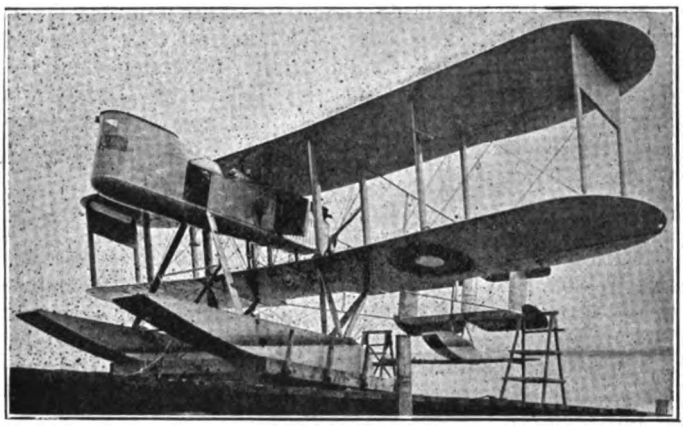


FIG. 5—A PONTOON PUSHER SEAPLANE OF THE FAST SPEED SCOUT TYPE WHICH WAS DESIGNED, MANUFACTURED AND PERFECTED DURING THE WAR

Most of the women employed on mechanical work were used in the assembly of airplane wings, but they were also extensively used in the metal and machine shop, in the wing covering department, in the sawmill, in the hull shop, in painting, in sub-assembling, in inspection and in the storeroom.

A similar training course was conducted in the factory for the enlisted men who were to be sent abroad for assembly and repair of seaplanes.

DEALINGS WITH EMPLOYES

In dealing with employes the theory that every employe had the right of appeal to the Manager was followed. In most plants a man's future and happiness are dependent upon his immediate superior's judgment. Or-

Digitized by Google

dinarily that judgment is sufficient and is just, but it frequently is not, and it was considered good business to have a department where someone who was not responsible for production and under the pressure that it implies might fairly consider both sides of each dispute and render an ex-parte decision. Since the Manager was too busy to assume this work personally, this responsibility was placed in the Employment Department, where grievances and charges of unfair treatment were regularly considered as matters of highest importance to the construction of seaplanes. Furthermore the Employment Department passed finally on nearly all rate changes, transfers, all discharges and draft exemptions.

Such a policy may have encouraged fault finding. That which was at bottom constructive and that which was not had to be distinguished. There was dependence on the department for straightening out difficulties. After the armistice was signed, when the plant was cutting down its force, those who so desired were helped to find other work.

Utilization of the Plant

At the time the plant was first projected, it was not known definitely what planes would be put into production therein, but it was designed practically with the idea of manufacturing training planes. Early in October the supply of training planes being assured and the supply of service flying boats being in doubt, it was decided to put into production an order of fifty twin-engined flying boats of the type known in England as F-2-A and in the United States as the Curtiss model H-16.

The engineering data were obtained from the Curtiss Aeroplane & Motor Corporation. To discuss the engineering problems involved, it is perhaps necessary to show the relation between the Naval Aircraft Factory, the Navy Department and other airplane factories. The Naval Aircraft Factory was designed to supplement, not to compete with, privately owned factories, its after-the-war future being intended for the development of new and experimental models. During the war its function was to be practically one of production. Located as it was in the Navy Yard and in charge of an officer known as the Manager, it was necessary for the Manager to be under the Commandant of the Navy Yard insofar as military matters and matters of general external policy were concerned.

Digitized by Google

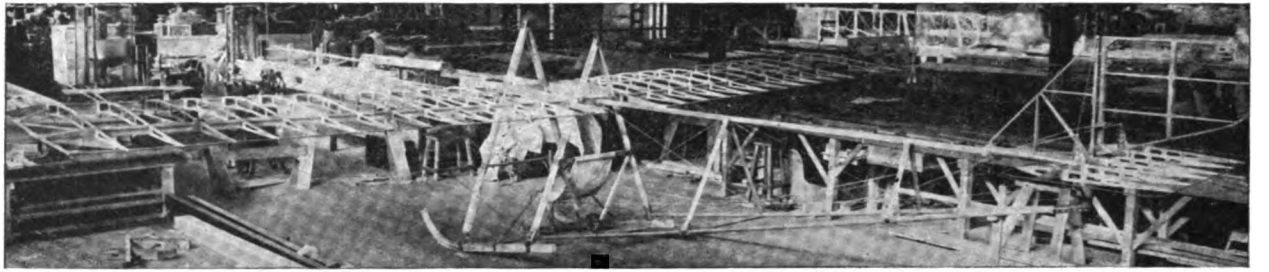


FIG. 6—SKELETON OF A SMALL PLANE BEING DEVELOPED FOR FLYING FROM A BATTLESHIP
It Is a 26-Ft. Span Monoplane and Complete with Pilot Ready for Flight Weighs Less Than 600 Lb.

Digitized by Google

The Bureaus of the Navy Department provided an independent inspection service at the Naval Aircraft Factory under the general direction of the Bureaus, just as the same service was furnished to privately owned factories. Communication with other plane factories was direct on matters not involving the inspectors' interests directly and correspondence was through the inspectors under the same conditions as those imposed upon private manufacturers.

Engineering Problems Involved

One of the principal problems of the Engineering Department was to apply the practice of part design for matching production to the manufacturing problems of the factory, and in the second model put into production, the F-5-L, a considerable difference was made to facilitate manufacture in many features. For example, metal fittings were designed to avoid as far as possible the use of drop forgings, as material for the former was easily obtained, easily worked and welded and would lose little strength if abused. Fig. 8 is a typical example. Often

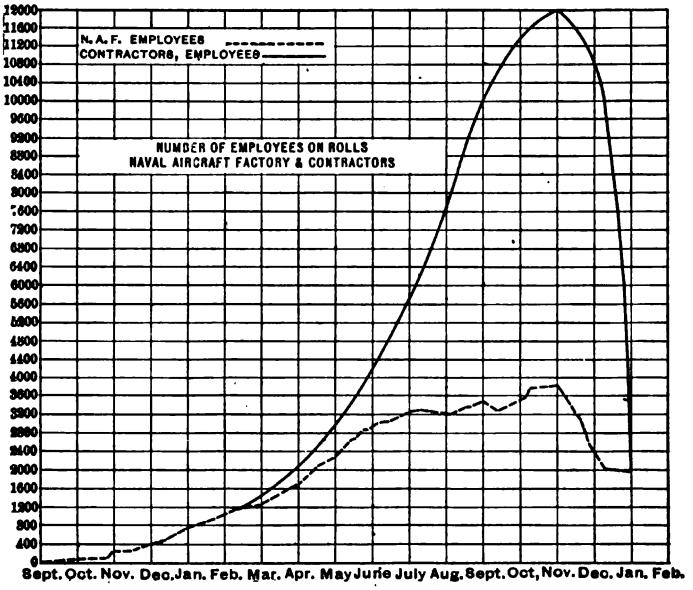


Fig. 7—Chart Showing a Constant Increase in the Number of Employes Up to the Time the Armistice Was Signed, the Solid Line Indicating Those Employed at the Factory and the Dotted Line Those Employed in Contractors' Plant

Digitized by Google

the most complicated fittings were so designed that they could be assembled, drilled, brazed, etc., by women. In the hull of the first model there were about fifteen different kinds of strap fittings for securing stanchions to each other and to the longerons. By reducing the number of different kinds of fitting, the number of dies, tools and jigs for their production was reduced, it was easier to

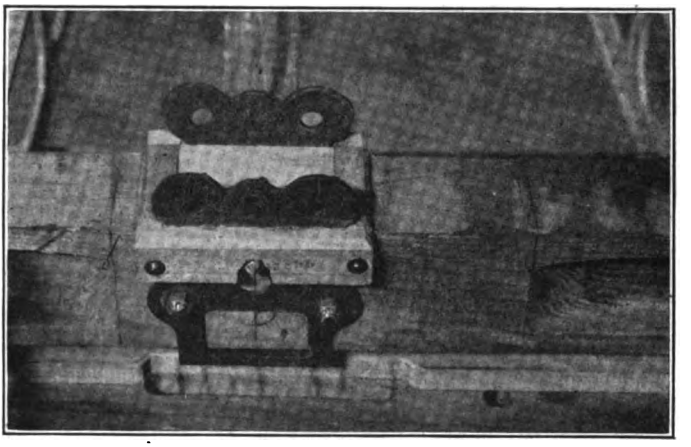


FIG. 8—A TYPICAL F-5-L FITTING USED ON THE WING BEAMS
Note That It Is Strap Iron Cut from a Flat Pattern

supply the shop and there was less opportunity for confusion; hence "average fittings" were designed so that some one kind of fitting could be applied to two or more different places. The result of this practice was that no fitting seemed exactly to fit, but outside of the loss in appearance the net result was a gain. Fig. 9 shows some typical average fittings.

In many cases, particularly at first, substitutions were necessary on account of lack of specified materials or parts. The Engineering Department was called upon to suggest and to pass on substitutes. Many times reference to the stress diagram enabled a simple substitution which saved a great deal of time and aided production. All such substitutions were, of course, taken up with the proper Bureau of the Navy Department and authorized.

THE ENGINEERING DEPARTMENT AND PRODUCTION

In getting the factory into production, this service of the Engineering Department was of inestimable value;

Digitized by Google

also in the investigations of spiral grain and the use of laminated members for struts and wing beams. Early practice dictated that struts and wing beams should be made in two pieces and lightened. The difficulties in the way of getting materials of the proper quality in the

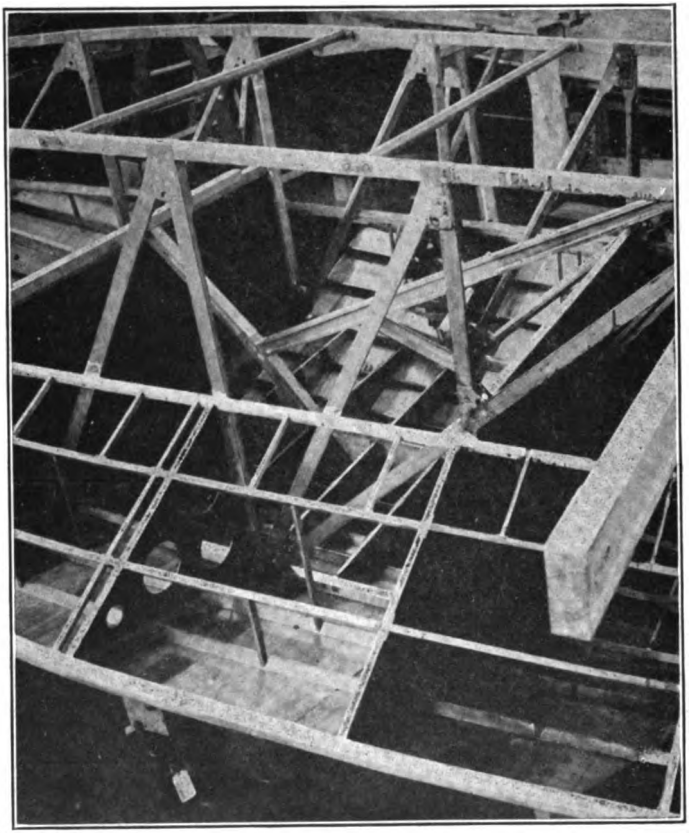


FIG. 9—MANY OF THE HULL FITTINGS WERE SIMILAR BUT NECESSITATED DIFFERENT DIES, PATTERNS, ETC.
Hence "Average Fittings," Several of Which Are Shown, Were Designed

necessary large sizes finally brought about the adoption of laminated pieces. Struts, for instance, were made with three laminations, and each lamination might be in two pieces, making six-piece struts. Wing beams were at first spliced, then laminated, and then the laminations

Digitized by Google

were spliced, and finally instead of two laminations three were used. Examples of each are shown in Figs. 10 and 11.

In working out this practice it was found that apparently good struts would warp or in testing would fail

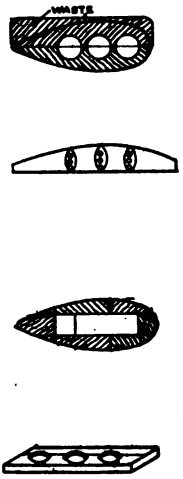


FIG. 10—BUILT-UP LAMINATED SECTION STRUTS

These Were Designed to Save Material and, Having a Uniform Section, Were Easier to Construct. The Upper Two Views Are a Section and Plan View of the Old Type Two-Piece Tapered Section Strut That Required a Large Amount of Material and Much Hard Work. The Next One Is a Section of the New Six-Piece Type in Which Small-Section Material May Be Used, While the Bottom View Shows the Lightened Center Section

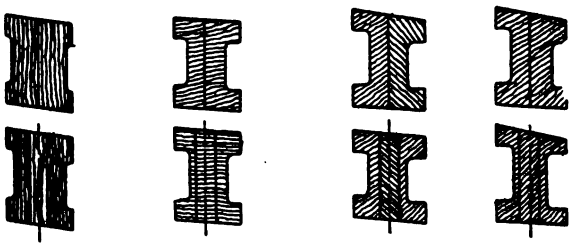


FIG. 11—METHOD OF BUILDING UP LAMINATED BEAMS WHICH WERE FOUND TO BE BETTER THAN SOLID BEAMS AS THE POSSIBILITY OF DEFECTS IN ANY ONE PART DECREASED

The Upper Row Are of the Two-Piece Construction and the Bottom One Shows the Three-Piece Construction

under small loads. Investigation disclosed the fact that the laminations must be of equal density to avoid these faults. For instance, in the two-piece strut if one lamination is of greater density than the other, the lamination of light density will yield under load more readily than the heavy lamination, thus throwing all the load on the

Digitized by Google

heavy one and bringing about early failure. Further study made it necessary to match not only in density but in grain, as is illustrated in Fig. 12.

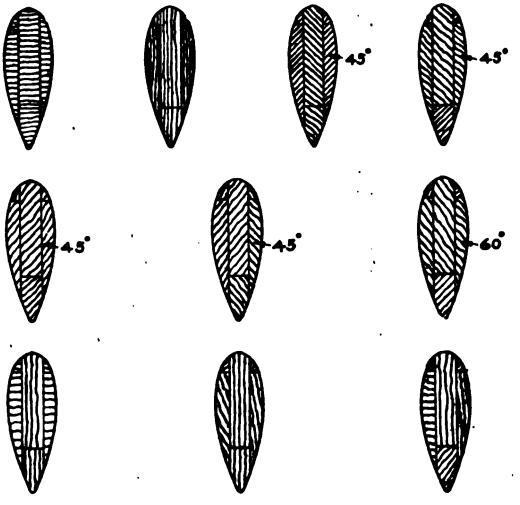
The Wood Technology Section was faced with the problem of discovering why during the winter from nine to ten o'clock every morning the steam-bent spruce and ash stringers would start breaking; one morning five bent members broke within half an hour. Investigation developed the reasons. It had been customary to allow the temperature in the plant to drop during the night to 50 deg. fahr. and starting at seven o'clock in the morning the temperature was brought up and by nine o'clock would be normal (65 deg. fahr.) The wood could not conform so rapidly to the changing atmospheric conditions, and the attempt to conform introduced internal stresses which broke the pieces. Thereafter the night temperature was held at the level of the day temperature and the trouble disappeared.

Considerable difficulty was experienced in getting satisfactory wood inspectors, due to the refined requirements. Defects that were not important to the commercial inspector of lumber or inspector of wood parts were found to be of prime importance in the aircraft factory. The question of strength was, of course, paramount, and thus it was necessary to discover hidden defects, and hidden defects are quite common in spruce.

Wood Defects a Problem

Three of these defects difficult to observe are pitch pockets, spiral grain and compression failure, none of which was very clearly recognized before the war. A typical example of spiral grain is shown in Fig. 13. Spiral grain is exceedingly difficult to detect, particularly in fresh cut material and is exceedingly treacherous, especially under shock or impact. This defect was given magnified importance at one time, but even after the excitement had subsided its danger was appreciated and has been minimized largely by the practice of laminating. A piece containing spiral grain will split straight along the growth grain, but will cleave at a distinct angle across the growth grain. It is discovered by looking for indistinct and sometimes nearly invisible veins of sap. The Engineering Department made a long series of tests in the study of spiral grain and with the strength data obtained and after a study of the stress diagram, spiral grain toler-

Digitized by Google



Laminated Struts Would Warp if the Grain in the Laminations Were Not Balanced. This Shows the Correct Method of Balancing the Grain. The Ideal Types Are Shown at the Top with the Acceptable Ones in the Middle and the Non-Acceptable Types Underneath

FIG. 12—TYPICAL EXAMPLES OF THE USE OF LAMINATED SECTIONS FOR AIRCRAFT STRUTS

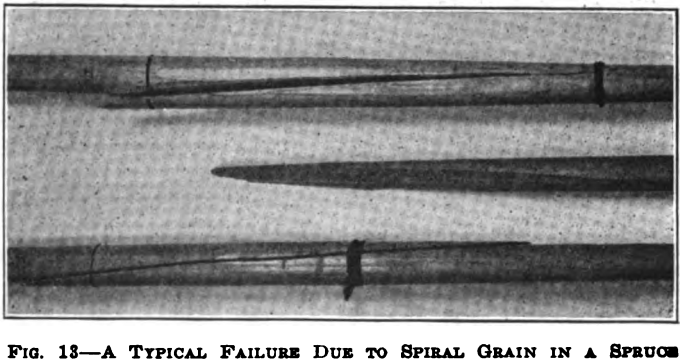


FIG. 13—A TYPICAL FAILURE DUE TO SPIRAL GRAIN IN A SPRUCE STRUT

Digitized by Google

ances were modified and reduced, which greatly facilitated the production program.

Bolt Practice

In the design originally put into production in this factory, the variation in diameter of bolt was by 1/32 in. and in length of bolt by 1/16 in. As these bolts were all of special dimensions and of special stock, heat treated and electroplated for protection against corrosion, and as the number of sizes was great, production difficulties and complications arose due to long parts lists, numbers of drawings, specifications, contracts, stockbins, stockcards, etc. Therefore, five diameters were adopted as standards by the Department, namely 3/16, ¼, 5/16, ⅜ and ½ in., and the variation in length was made by ⅛ instead of 1/16 in. By this means the number of sizes was reduced enormously.

In the early practice castle nuts and cotter-pins were used on all bolts. These bolts were, of course, hardened, and it was exceedingly difficult to drill them on assembly, requiring much time, causing the breaking of many drills, and frequently on wing panels resulting in damage to the fabric which required patching. This practice was immensely simplified by the use of washers under all nuts bearing on metal surfaces; and nuts bearing on wood surfaces were headed over unless it was necessary to have them readily removable. This reduced the assembling time of many assemblies and further simplified the production problems.

How Material Was Obtained

At the time the factory was projected the markets had been pretty well cleared of available stocks and the operation of the priority system had not been satisfactorily worked out by the Government, so that the material problem was exceedingly difficult. The factory being a beginner had absolutely no stocks. It was necessary to buy all materials through the purchasing routine of the Navy Department, buying on specifications and only after the widest possible competition. Materials were just beginning to come in when the freeze-up and traffic paralysis occurred, and much valuable time was lost.

Another problem faced the Supply Department, due to the policy that the Naval Aircraft Factory should add to the aircraft industry. It followed that as the principal

Digitized by Google

dealers in aircraft materials had all, or nearly all, of the work they could handle, it was necessary to develop new sources of supply. A force of traveling representatives was kept on the road to interest new plants and to investigate the capability of bidders to deliver goods, and they were later used to expedite production in these sources. Particular attention was paid to the task of teaching these vendors how to manufacture materials and parts to meet specifications and requirements of the aircraft industry.

This section was supplemented by a traffic and follow-up section, which attended to the routing of traffic and following it on the road, and the factory, like all other aircraft factories, operated a "suit-case express" to meet its own urgent requirements and those of its sub-contractors.

The Naval Aircraft Factory is a larger institution than the entire Navy Yard was before the war. It used in manufacturing over three times the quantity of lumber that the League Island Navy Yard uses at the present time. It handled more shipments per day than even the New York Navy Yard handled before the war. Up to the signing of the armistice the lumber yard received 16,000,000 board ft. of lumber and stored it properly; 7,759,000 board ft. was used in manufacturing or shipped out to sub-contractors for the manufacture of hulls or parts; and there remained about 6,000,000 ft. in the yard at the cessation of hostilities.

Rail Shipment Undesirable

A perplexing problem was the loading of completed flying boats. On account of the large dimensions of the hull case, rail shipment was undesirable. Boats shipped by other manufacturers in this way having been damaged, shipment by canal barge was developed and proved successful, except, of course, in case of those planes shipped abroad from the factory. Every plane loaded at this factory arrived at its destination without damage due to shifting of cargo or other incident attributable to the method of securing it.

Source of Spruce

The spruce supply problem was solved by the Navy Department in contracting for New England spruce. This comes in smaller sizes than the Western spruce; but by laminating beams and struts and by splicing beam lami-

Digitized by Google

nations, the purchase of Army spruce at from $300 to $750 per thousand was discontinued and Navy New England spruce was taken at from $100 to $125 per thousand.

Changes in Construction and Design

Many changes in construction were necessary for a number of reasons. In spite of the utmost effort, drawings were frequently incorrect, because of insufficient data on the strength or nature of materials, because of hurried preparation to meet requirements of the shop, or incomplete checking because of limited time. There were also changes in design to permit substitution for materials not obtainable, or eliminate weakness developed by test, or provide improvements found necessary by overseas use, reduction in weight, or to further standardize or reduce the number of parts. All these changes had to be met with the least interruption to the shop schedule which had been prepared for the parts in question.

The variety of materials required was greater than would at first be supposed. Many of these were, both in character and treatment, unfamiliar to the workmen, necessitating experiments frequently resulting in ruined parts. All materials passed through rigid inspection, not only on receipt at the factory, but after each stage in manufacture.

Special Tools and Fixtures

Methods, tools and appliances were in many cases new or untried, or adaptations from other trades, as, for example, an emergency blanking die, good for from 100 to 500 pieces, which could be manufactured in our toolroom in from 12 to 24 hr. The die was mounted on a base and separated therefrom by spacing blocks somewhat thicker than the material to be punched. The punch was a loose piece of machine steel guided to the die by the guide block, held in position above the die. This device was used on ordinary stamping presses for material to and including ⅛ in. thick.

Jigs and fixtures for bending, welding, cutting, drilling and testing, frames for setting up an assembly, were developed and built up by crews in each shop designated for the purpose.

A feature new to most of our workmen was the small tolerance permitted in wood, as well as in metal, to secure minimum weight and avoid hand-work in assembly.

Digitized by Google

The floor space allotted to the various shops was based on the speed requirements indicated by the program chart, and so arranged that the flow of material was as much as possible in a forward direction, with a minimum of back-tracking, and sub-assembly storerooms were located at convenient points in the line of flow of material, between the shop where the part was manufactured and the shop where it was used. In this manner large storage areas were avoided and the sub-assembly storerooms were continually under the eye of the shop foreman, while records of their contents could be reported daily to the manufacturing office, where the records were kept and orders so issued so as to keep the various crews busy, to avoid accumulation of parts, thus saving floor space and delivering finished parts and sub and major assemblies when, where and as required.

How Production Was Maintained

The first order was for fifty seaplanes to be delivered by Aug. 1, 1918. Early in March a program was mapped out after consultation with the foremen of the shops, showing when we could reasonably expect to complete the first plane, then in process of construction. With that as a beginning date, a curve was drawn to July 1, the date of completion, showing the number of planes to be completed week by week, increasing as the men became expert in their work, more men could be secured and trained, more rapid and uniform supply of parts secured, and the organization improved. From this program for finished planes there was prepared a schedule showing dates on which were to be completed each hull, each set of panels, etc. From this in turn were scheduled the dates on which the necessary number of metal, wood and other parts would be required, then the dates on which materials for such parts should be delivered and tools for their manufacture secured. These fundamental schedules were placed in the hands of the Supply Department, Employment Department and foremen, and systematically followed up, the progress made in securing men and materials being followed by progress curves, which were compared daily with the schedules showing like requirements. This method not only gave warning ahead of time of what would be required by each foreman for the accomplishment of his program, but also told him what would be required from his shop on any given date.

Digitized by Google

Drawings and instructions were scheduled in the same manner, which made it possible to concentrate first on drawings for parts which required longest to manufacture or which were needed earliest in the construction of the plane.

In the usual manner the manufacture of wood and metal parts, assembling of panels and hulls, painting and final assembling were assigned to separate shops; the work of each separate shop being further subdivided by crews doing similar work, every effort being made to select for these crews men or women who were, by previous experience or shop training, familiar with the particular type of work.

As an illustration of the advantage of subdividing the work so that each man was given a job which he could repeat day in and day out, there is cited the method of building hulls. The earlier hulls were each built by separate crews, each building a hull in its entirety, and as a natural result each man in the crew performed such a variety of work that no one did enough of any one thing to learn how to do it well and rapidly. The shop was full of hulls in various stages of completion, it was with great difficulty that the materials required by each crew were kept on hand, and more or less confusion was the result. There were nine of these crews, varying in size from 15 to 25 men, and the first step in separating the job into its component parts was to select the operation requiring the greatest number of man-hours. This was found to be the planking of the bottom of the hull. At first this operation required a crew of 20 men, working 4½ days, or 900 man-hr. By increasing this crew to 40 men, the time was reduced to one day or 400 man-hr., the men working without interfering with each other or any other crew, as the hull was theirs for that day.

How Time Was Saved

The construction of the hull was divided into such operations as framing, brace wiring, planking, etc., each of which covered a similar kind of work. These operations were then grouped so that as many crews as possible could work on the hulls at the same time without interfering with each other, after which the various crews were built up so that each group of operations was completed in one day. By this method the time required to complete a hull was reduced from 41 to 16 days, which not only saved time and men, but floor space as, by pro-

Digitized by Google

viding sixteen berths, we secured a delivery of one hull per day; by apportioning the construction of the hull to 16 crews, each doing a day's work on each hull, it was practicable, by having 16 planes under construction, to have all planes simultaneously undergoing separate operations, and have each crew move from one plane to the next at the end of each day, thereby giving place to the crew performing the next operation. The speed of delivery was later raised to more than one plane a day by increasing the number under construction at one time.

The same method was followed out in the final assembly of planes. Whereas the first plane required for its final assembly 50 days, with a crew of 35 men, the second 27 days, the third 17 days, this time was finally reduced to 7 days. In the subdivision of work in final assembly, every effort was made to remove from the plane such work as could be done elsewhere; as, for example, the wiring of the hull for heat, light and ignition. At first this required 114 man-hr. per plane. By assembling parts on benches, this was reduced to 73 man-hr. per plane. The time on the plane itself was at first 30 hr. and was later, by the use of jigs, reduced to 10 hr. The advantage was not only in the reduction of labor cost but also in the completion of the work in a short time. The hull is delivered to the final assembly floor with the wiring-board in place. This board is removed, placed on a jig, and in 1½ hr. is ready to replace on the plane. In 30 min. after the wiring-board is completed on the jig, it is replaced in the plane and all dependent operations may proceed; the wires having been previously cut to gage, terminals fitted and soldered, wires assembled by charts, and errors practically eliminated. It may be mentioned that the work on this jig covered three systems of wiring, namely, heat, light and ignition; and that women learn to do this portion of the work in a day.

Another example of the subdivision of labor is in the construction of pontoons, which, under the first method of having one crew build the pontoons complete, required 279 hr. per pontoon. By dividing the construction into various operations, each performed by a separate crew, the time was finally reduced to 40 hr. per pontoon.

As to progress in cost reduction, it may be stated that the factory cost, including overhead, of the last twenty boats, out of the first order for fifty, was less than half that of the first ten, and was considerably less than the

Digitized by Google

price at which the Navy was buying these boats from other plane factories.

Cost Records as Essential as Planes

One of the chief reasons for the establishment of the Naval Aircraft Factory was to obtain data on the cost of aircraft and aircraft parts for the information and guidance of the Navy Department and its Bureaus in dealing with private manufacturers. It was obviously necessary, therefore, that all those elements of cost with which the private manufacturer is burdened should appear in the course of the output of the Naval Aircraft Factory. In other Government-owned establishments a great share of the burden is charged direct to operating appropriations, under the Navy Department, and does not appear in the cost of output. The Naval Aircraft Factory, being a new institution, it was arranged to introduce a system of accounts and of procedure which would permit the inclusion of all overhead, and the scheme was successful. The overhead contains interest on plant, depreciation (after the first year) and allowances for all the other standard items except profit and taxation. Even the salaries of Naval officers are included in the costs.

In this Department, as in the Supply Department, it was necessary to conform to statute, Navy regulations and the requirements of the Treasury Department, and of course in such a way as not to interfere with the establishment of a thoroughly practical commercial cost-keeping system. It will readily be seen that its immediate and difficult problem was to observe these multitudinous requirements with a perfectly green crew. Timekeepers, for instance, were recruited from the industrial force of milk wagon drivers, trolley car conductors, etc., and the word chaotic is the only one to use in describing the early condition which, however, due to the energetic and clear-headed work of the Accounting Officer, was soon put on an orderly basis, with the result that the Naval Aircraft Factory payrolls and other financial returns were made promptly and accurately and in conformity with the regulations.

Expense was distributed to the different departments, according to its nature; that is to say, building charges on the basis of space; machinery and equipment charged on the basis of equipment supplied; supervision and similar charges on the basis of services rendered. It was

Digitized by Google

and is the intention eventually to apply expense by a machine rate method, but it being necessary to get started quickly, a man-hour basis of distribution was adopted to begin with and is still in use.

Every worker has a time-card for every job every day, and every item issued from stores is covered by its own separate stores requisition. Costs are kept by production order and are separated out and reported by appropriations and according to all the detailed requirements referred to in general above.

Space forbids discussion of the problems involved by the exclusive cognizance of the Bureaus of the Navy

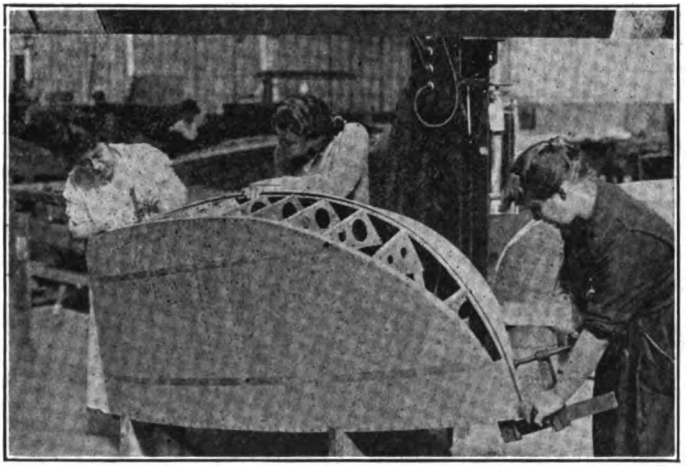


FIG. 14—AT FIRST 279 MAN-HR. WAS REQUIRED IN PONTOON CONSTRUCTION
By Dividing the Work Into Operations, of Which This Is One, the Time Was Reduced to 40 Man-Hr.

Department over its own appropriations. If space allowed, a statement of the various restrictions would be as interesting as their application was difficult.

OUTSIDE CONTRACTS HANDLED SEPARATELY

The term contract manufacturing is intended to cover the production of hulls, assemblies and parts by private manufacturers for assembling at the Naval Aircraft Factory, as called for by the enlarged program referred to above. This required a separate department. It will probably be agreed that it is much more difficult to hire

Digitized by Google

other plants to do one's work than to do all the work oneself, because of the difficulties in placing orders, contractual relations, getting the contractor to manufacture the goods as wanted and deliver them when wanted, the difficulties introduced by transportation, to say nothing of the difficulty in maintaining quality and holding down prices.

In this particular case the problem was much more difficult because none of the contractors understood the work and they and their workers had to be taught. Although every effort was made to choose sources already completely equipped, this was not practicable, and it was necessary to add to contractors' equipment in many cases and to a considerable extent. The war conditions made it hard for private manufacturers to get material and labor and to hold their labor. Transportation problems were difficult beyond all expectation and altogether the manufacture of parts in subcontractors' plants is an undesirable policy. In defense of it, there can be said this, that the Naval Aircraft Factory got its parts almost as fast as they were wanted and that by dint of exceedingly careful and thorough instruction, the required standard of quality was maintained. Also the Navy finds itself, now that the war is over, with a much smaller plant expenditure on its books than it would otherwise have had.

The policy in placing contracts was to select plants as nearly as possible properly equipped and of manufacturing experience which made their organization and personnel readily adaptable to the production of aircraft; also to establish for each part or assembly two or more sources in different localities, so as to protect the manufacturing program against interruption in supply, due to fire, labor, transportation or other difficulties.

In each plant was established a branch office of the Naval Aircraft Factory in charge of a Branch Manager, with production, inspecting and teaching assistants. Service was extended to the subcontractors in getting material and labor, because the Naval Aircraft Factory organization knew better how to deal with the bureaus of the Navy Department and with the other departments, commissions and boards of the Government.

Most of the contracts were made on a cost plus profit basis and, therefore, in each plant the Bureau of Supplies and Accounts established a Cost Inspector. No extraordinary difficulties were experienced by the Naval

Digitized by Google

Aircraft Factory in the operation of these contracts.

The reason for having a separate organization of the Contract Manufacturing Department was found in the fact that the manufacturing department of the factory proper was struggling with its own program and making good headway and it seemed better to establish a new organization than to interfere with and possibly destroy a satisfactory organization before it had acquired the stability of motion derived from experience and habit.

Later, as the original organization became stabilized, the disintegration of the Contract Manufacturing Department was begun. Inspection was first taken over by

FIG. 15—THE FACTORY HAD A PLANE READY EVERY TIME THE NAVY WANTED ONE
A Few Shown Awaiting Shipment

the Engineering Department. Later the Material Section of the Manufacturing Office took over general charge of the entire manufacturing program. Again, the largest source of metal parts and assemblies, which had at first been under the cognizance of the Contract Manufacturing Department, was shifted over to the Manufacturing Department and one of its superintendents placed in charge of the work there. The cessation of hostilities found the Contract Manufacturing Department reduced to about half its original size and scope.

BACK TO A PEACE BASIS

The present date finds the Naval Aircraft Factory reduced in volume of work and changed in its policies

Digitized by Google

and class of work. At the time the armistice was signed there were employed in the Naval Aircraft Factory proper some 3740 persons and in the plants of subcontractors nearly 8000 more. Work has been discontinued in the subcontractors' plants and the force at the factory reduced to 2000. The large new assembly plant has been converted into an aircraft storehouse. The storehouse building is being filled with raw materials and partially or wholly manufactured parts and assemblies. The large-scale production of boats has been stopped. Those boats which were so far along as to make it good business for the Navy to protect its investment by completing them are being finished and being good standard craft will be suitable for the peace-time uses of the Navy.

The factory is giving its attention to the manufacture of training planes and to the designing and construction of experimental models; developing the art of flying. Fig. 14 shows some of the work that has been and is being done.

In the stopping of work in subcontractors' plants the policy was adopted of effecting an adjustment which would be mutually satisfactory. No arbitrary cancellations were issued. So far as possible opportunity was given the contractor to taper off his work and to return to peace-time activities without any greater shock or disturbance to his organization than could be accommodated by its inherent elasticity.

The Naval Aircraft Factory is indebted largely to the automobile industry, to automobile engineers and to this Society for the help it has received in numberless ways, appreciation and thanks for which it is a privilege to extend.

Digitized by Google

AIRPLANE AND SEAPLANE ENGINEERING

By Commander H C Richardson[1], U S N

AFTER stating the general problem confronting the Navy relative to the use of aircraft in the war, the author outlines airplane design in a general way, discussing the principal factors involved and applying them to a definite example to illustrate the methods of computation used.

The effects of different arrangements and disposition of wings and other elements on performance and stability are indicated, covering the effects of monoplane, biplane, triplane, gap ratio, aspect ratio, stagger, dihedral, etc. Airplane performance is treated as depending upon the horsepower required and the horsepower available. Horsepower required is shown to depend upon "planes" horsepower and "head-resistance" horsepower. Horsepower available is shown to depend upon the mutual influence of the engine and the propeller characteristics, the importance of suitable revolutions for the speed of advance being pointed out. The advantage of gearing down is demonstrated to be desirable for planes of moderate speed.

Seaplane float design is discussed at length as to both form and structure, and the important influence of this element in seaplane design is shown by data from model-basin tests. The horsepower required and available when the seaplane is running on the surface is specified. The influence and effects of steps, ventilation, V-bottoms, etc., are taken up. The value of model-basin tests is shown, and the fallacy of requiring the beam to be directly proportioned to the load is made evident. The merits of the central-float type of construction are explained; also the advantage of the longitudinal method of bottom framing. Naval seaplanes used during the war are illustrated and described, including the NC-1, the predecessor of the NC-4, which was the first airplane to cross the Atlantic.

The problem confronting the Navy was largely determined at the time the United States entered the war by the fact that the operations of the German and Austrian

[1]Superintending constructor of naval aircraft, Buffalo district, Buffalo, N. Y.

Digitized by Google

fleets had been reduced principally to minor raids from the fleet bases at Kiel and Pola, and the only real seagoing operations comprised the activity of submarines.

The work of the seaplanes, therefore, was primarily reduced to that of cooperation with the fleet in reducing the submarine menace. This naturally led to the establishment of coastal stations in France, Italy, England, Scotland and Ireland. In these operations it was possible to operate seaplanes from shore bases in practically every case, and the development of work with the fleet became a minor consideration.

Some of the seaplane bases, however, were sufficiently close to enemy territory to be within raiding distance of enemy planes of both land and water types, and it became necessary for the Navy to extend its activities to the use of land planes for the protection of seaplane bases, while Naval aviators also participated in big bombing raids on German and Austrian territory.

I refer to these matters in this general way, not to describe the activities, but to show that in Naval work both land and water planes were used, and why the Navy problem was in general restricted to operation from shore bases rather than operation from ships. Activities, however, were not confined to shore bases in Europe. Stations were established on the Atlantic coast, principally for the purpose of submarine patrol and for convoy work from the principal ports from which our troops and supplies were sent abroad.

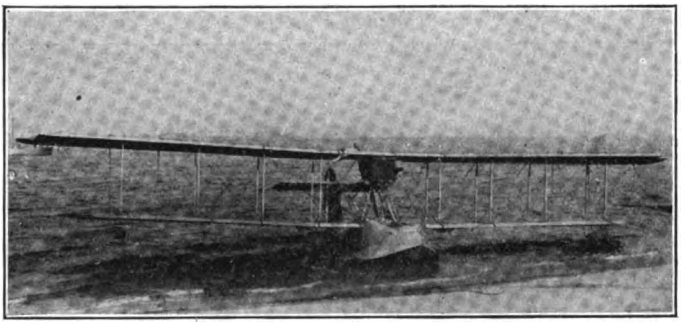
Types of Planes Developed

The work of seaplanes abroad was that of submarine patrol and convoy work, and this having been determined, all efforts were made to obtain the most suitable seaplanes for the service. The principal work was done with two types of seaplanes, namely, the HS-2, the single-motored plane developed from the HS-1, and the H-16, a copy of the English seaplane of the same type developed as a result of Commander Porte's experience with the original America and subsequent types developed therefrom. Finally, the F-5-L type was developed from English designs for manufacture in this country by the Naval Aircraft Factory at Philadelphia. The HS-2 and the H-16 have proved well suited to the work required, but the F-5-L did not enter production

Digitized by Google

early enough to get into active service before the armistice was declared.

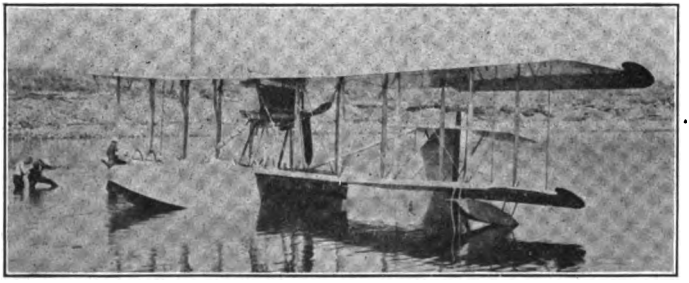
The Navy did not attempt to develop land plane types, but accepted and used those which had been developed



THE HS-2 NAVY SERVICE PLANE WHICH WAS DEVELOPED FROM A TWIN-ENGINED SEAPLANE ORIGINALLY DESIGNED FOR THE ARMY

and produced for the Army, adopting for this purpose the English Handley-Page, the Italian Caproni, and the Army DH-4 and DH-9.

In order that pilots should be trained for this service, it was necessary to adopt training planes, and for this purpose the Navy developed and used the Curtiss N-9,

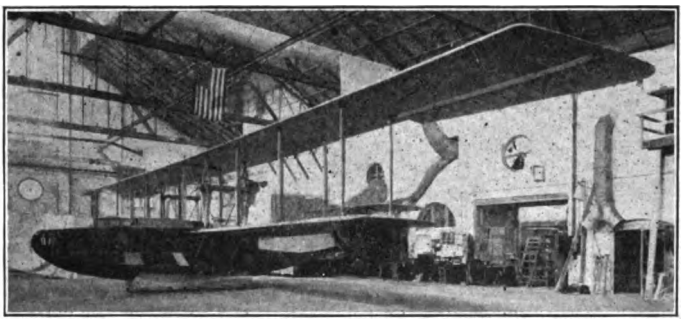


THE HS-2-L SEAPLANE USED BY THE NAVY

the R-6 and the R-9, the Aeromarine and Boeing seaplanes and the F-boat, and also experimented with a number of miscellaneous types, such as the Gnome scouts, both biplane and triplane of Curtiss and Thomas manufacture, and the Gallaudet D-5. The most successful

Digitized by Google

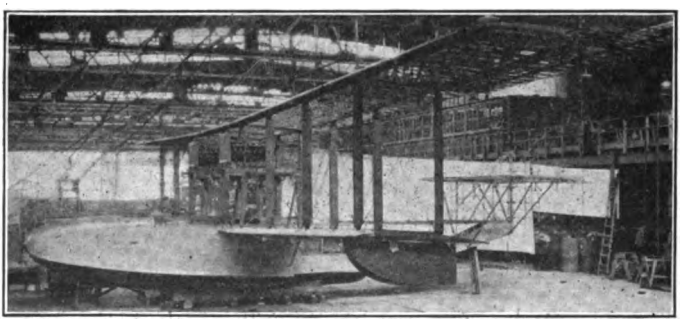
of these training planes was the N-9, particularly after the original float had been modified and later on after the substitution of the Hispano 130-hp. engine for the OXX 100-hp. engine. This plane was a biplane tractor with a single center float, having wing-tip balancing floats. It was remarkably strong and could perform



A THREE-QUARTER FRONT VIEW OF THE H-16 SEAPLANE

practically all sorts of maneuvers. Although in training work it was frequently wrecked, there were remarkably few deaths resulting. This I attribute to its moderate speed, great strength of construction and tractor arrangement, which made it suitable for training purposes.

As soon as it was determined that seaplanes of the



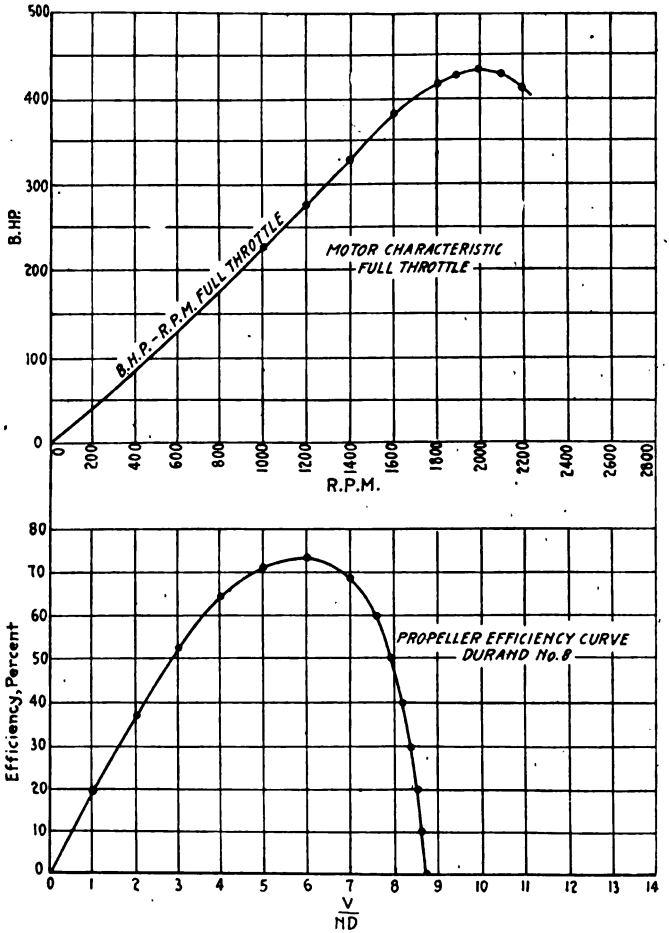
THE F-5 SEAPLANE USED BY THE NAVY

flying-boat type were to be used in service it became necessary to provide preliminary training in a type of seaplane which more nearly represented the conditions of operation of the big boats. For this purpose the F-boat

Digitized by Google

originally developed by Curtiss for sporting and for naval use was modified and adapted to instruction purposes.

I shall later on describe and illustrate the principal types referred to.



TYPICAL MOTOR CHARACTERISTIC AND PROPELLER EFFICIENCY CURVES

So far as the aerodynamical and mechanical features of construction are concerned, seaplanes differ very little from airplanes, the principal difference being the use of

Digitized by Google

the landing gear suited to operation from the surface of the water instead of from the land. The proportions are, naturally, somewhat different, and the performance is different, primarily, because of the greater inertia due to the increased weight involved in the seaplane construction. But bearing this in mind, the details of construction of seaplanes are substantially the same as those used in airplanes.

Factors Affecting Performance

It will now be of interest to consider the principal factors which affect performance, as it is necessary to understand these completely to develop a design which shall perform according to the requirements of the service intended. For the purpose of illustrating the factors involved I have prepared a set of performance curves, which I believe will give a clear insight into this phase of the problem. The complete calculation of the curves shown is given in the Appendix, together with the formulas involved in the computations.

The performance in power flight is determined by the horsepower required and the horsepower available, and, of course, the latter must always exceed the former or power flight is not attainable.

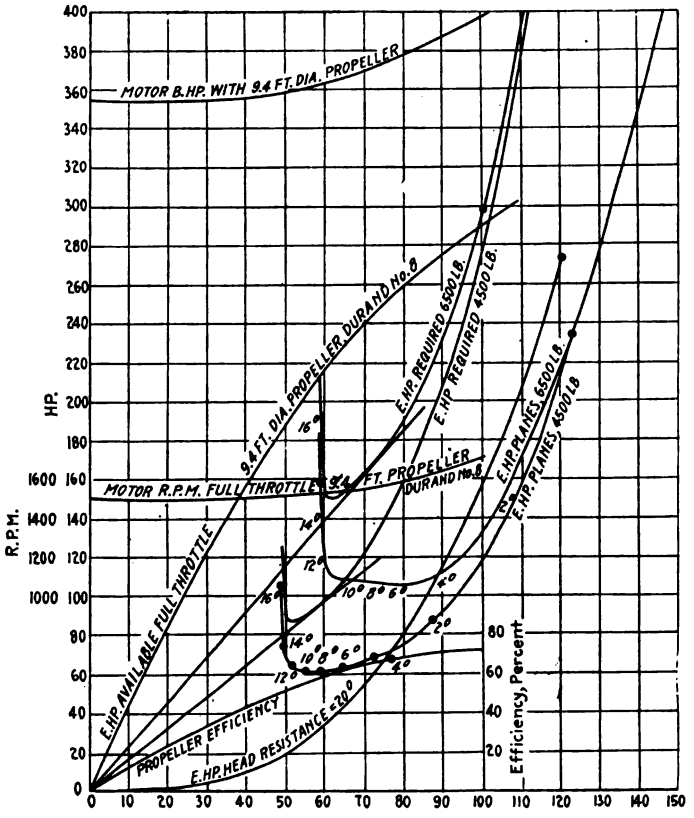
In determining the power required there are two principal factors involved. The first factor is that of the horsepower required to propel the planes with their load in flight. This I term the plane's effective horsepower. To determine it, it is necessary to know the form and disposition of the wing surfaces used, as well as the aerodynamic characteristics of the wing section employed. The lifting power of the wing depends on the area and the square of the speed of advance, and its resistance is also in proportion to the area and the square of the speed of advance, the speed of advance being the speed relative to the air itself and not the speed over the ground.

The lift of an airplane surface and its resistance to advance are determined by the lift and drift factors, which vary with the type of section used and also with the angle of attack at which the surface is presented to the relative stream of air. It has been found by experiment that these factors are influenced by the proportion and arrangement of the surfaces, the best results

Digitized by Google

being attained with what is known as the monoplane surface.

Performance is improved by increasing the dimension of the wings in the lateral sense over that of the fore-and-aft dimension. The ratio of these two dimensions



HORSEPOWER CURVES OF THE RAF6 BIPLANE

is called the aspect ratio. As the aspect ratio is increased, it is found that the efficiency is improved indefinitely. But after an aspect ratio of 8 or 10 is attained the improvement in efficiency becomes less and less, and, practically, is not worth going after, because the dimensions become unwieldy and the gain in lifting power and

Digitized by Google

efficiency may be more than wiped out, due to the increased weight and resistance of the structure required in employing it. It is largely on account of this difficulty that the biplane and the triplane have been used where large lifting power is required, even though in the latter cases the efficiency of the surfaces is reduced because of interference of the air flow, which is found to depend upon the gap ratio. By this is meant the ratio of the distance between superposed planes to the chord length, or fore-and-aft dimension of the wings.

Where the leading edge of the upper plane is forward of the leading edge of the lower plane the efficiency is improved over that where one plane is immediately above the other, and conversely. This arrangement is referred to as stagger and the condition of positive stagger, that is, with the upper wing forward of the lower wing, is generally adopted with the view of improving efficiency. There are limits to its usefulness because of the obliquity of the trussing involved.

Stagger may be adopted for various reasons, such as correcting the balance of an airplane in which the actual location of the center of gravity does not conform to that originally contemplated, or in order to improve the view of the pilot or observer, particularly if the latter is also a gunner.

The efficiency is improved if the upper plane has a greater lateral dimension than the lower plane. This disposition is known as overhang. There are limits to the extent to which this can be employed, on account of the structural difficulties involved.

In the normal type of construction, the front and rear edges of the wings are parallel, although it is found that tapering the wings to a smaller fore-and-aft dimension at the wing tip improves efficiency. This arrangement is not satisfactory from a manufacturing point of view, as it involves different sized ribs at every station in the wings. All the above considerations have to be taken into account in determining the form and proportion of the wing surfaces.

Another factor is very important, that is the travel of the center of pressure on the wing surfaces. It is found that where wings have a cambered surface, which is usual in airplane construction because of the superior lifting power, the movement of the center of pressure is such as to cause longitudinal instability. Various

Digitized by Google

devices have to be employed to overcome this. The most satisfactory and usual method is to employ an auxiliary surface at the tail of the airplane called the horizontal stabilizer, and the best conditions for stability are found when this rear surface has a smaller angle of attack than the wing surfaces themselves.

This difference of angle between the wings and the horizontal stabilizer is termed "longitudinal dihedral." The stiffness or steadiness of an airplane in flight depends on the area, proportion, section and angle of the rear surface. Where great stiffness is desired, this rear surface may even assume the proportions of a second set of lifting surfaces which may be of monoplane or biplane arrangement, usually of smaller dimensions than the main planes. Where the rear surfaces are increased to nearly the proportions of the forward surfaces, the tandem biplane arrangement is approached.

For military purposes and for combating rough air conditions it is found desirable to have initial longitudinal stability, but it is undesirable to have this in a high degree on a military plane in which steadiness may be essential to the proper operation of a gun or of a bomb-dropping device. If the rear surface were completely fixed in relation to the forward surface it would be possible to proceed in horizontal flight at one definite speed only for the load carried, and ascending or descending could be accomplished only by increasing or decreasing the power, or by decreasing or increasing the load. These methods of control are not sufficiently accurate or active, and it is much more satisfactory to use additional surfaces, known as elevators, appended to the rear margin of the horizontal stabilizer, which by modifying the action of the stabilizer make it possible to proceed in horizontal flight at any speed from the minimum to the maximum flying speed, or to cause the plane to rise or descend. In some airplanes, in order to get the maximum of maneuvering ability, the horizontal stabilizer is reduced to a very small area; or, even, in some cases, is completely dispensed with, all being merged in the elevator.

In the original Wright machine lateral balance was maintained by warping the wings, but this method is unfavorable to strength in large structures, and the use of ailerons for this purpose has now become general.

In flight, airplanes are not always operated so that the trajectory conforms to the axis of the airplane, par-

Digitized by Google

ticularly when turning or when encountering side gusts, etc. As a consequence, unless what is known as the keel surface of the airplane is distributed equally above and below the center of gravity, there is a tendency for the airplane to roll one way or the other, depending upon the location of the center of gravity relative to the center of lateral pressure. To compensate for this effect, or to provide lateral stiffness under such conditions, it is usual to provide a moderate amount of what is known as lateral dihedral; that is, the wing tips are higher than the center portion of the wings; or else skid fins are placed immediately under or above the upper wings. These in general have the same effect as lateral dihedral. By modifying this arrangement the amount of lateral stability can be controlled to any desired degree. Again for military purposes it is desirable to have initial later stability, but not to such a degree as to interfere with controllability of lateral balance.

Directional stability is also affected by the location of the center of side pressure, depending upon its location fore-and-aft of the center of gravity. It is essential for steady flight that the center of lateral pressure at small angles of skew should not pass forward of the center of gravity. To accomplish this it is usually necessary to install a vertical stabilizer at the tail of the airplane. It is again desirable to have initial directional stability. And again, in a military plane, it is undesirable to have this to such a degree as to interfere with control of direction. As the airplane is symmetrical relative to the vertical fore-and-aft plane, it is unnecessary to provide any equivalent of the dihedral effect, and it is only necessary to append a rudder to the vertical stabilizer in order to control direction. In some planes, where extreme maneuverability is desired, the rudder itself, in the neutral position, performs the functions of a vertical stabilizer as well as that of a rudder, and no vertical fixed surface is used.

Location of Powerplant and Crew

Having given due consideration to the influence of the proportion, arrangement and disposition of the main supporting and control surfaces, it is next necessary to consider the service intended and the location of the powerplant and the crew. The possible arrangements are almost infinite, but in general it is desirable to locate the

Digitized by Google

pilot centrally where he will have a proper view to enable him to handle the airplane to the greatest advantage and this is particularly necessary in the combat plane. It is also essential that the gunner shall have as large and unobstructed a view as practicable, and that with the gun positions selected he shall be able to cover his arc of fire and as much of the surrounding sphere as is practicable, in order that there shall be no dead spots from which the enemy may approach without his being able to return the fire. This sometimes requires that the pilot himself shall be able to operate guns firing dead-ahead, or that additional gunners shall be placed so that they can cover arcs of fire not possible for the others to cover.

In bombing planes and, in particular, in night bombing ones, this requirement is of less importance, and the requirement that the bomb dropper shall have a proper view for the operation of the bomb sights becomes of prime importance.

In airplanes designed for long-distance flights or for bombing, it becomes necessary to have great power available and this requirement has led to the adoption of multiple-unit powerplants. Two, three, and as many as five powerplants have been successfully used for this purpose. The multiple-engine plane has the advantage that in case of damage to one powerplant it is usually possible to continue flight with those remaining; or, if still too heavily loaded to accomplish this, it is possible to glide for a long distance and thereby select a more favorable landing place, and often to avoid landing on enemy territory.

All these and many other considerations enter into the disposition and arrangement of the powerplant and fuselages, and these arrangements themselves have an influence on the performance of the wing surfaces because of interferences involved.

By winging out the powerplants a more favorable load distribution is imposed on the airplane structure and advantage is taken of this feature in designing the wing trussing. The effects of interferences and of the disposition and proportion of the wings or bodies and auxiliary surfaces are so complex that unless data are already available from similar designs, it is very desirable that the resistance and lifting power of the complete design should be determined from wind-tunnel tests of a model

Digitized by Google

carefully constructed to scale in every detail. Such model test is usually deferred until the design has approached some definite form after preliminary estimates have shown that it is capable of approaching the performance desired.

Form and Proportion of Wings

In preliminary estimates the influence of the form and proportion of the wings is carefully estimated, and from these estimates a fairly accurate approximation of the horsepower required for the planes is derived. To arrive at the total horsepower required, it is next necessary to consider the horsepower required to overcome the head resistance. In order to do so, it is necessary to have accurate knowledge of the resistance of all elements of the airplane structure exclusive of the wings, which are exposed to the action of the wind in flight.

To reduce the resistance of these elements to a minimum, streamline forms are adopted wherever practicable, and even the truss wiring is made up of streamline form; or, if this is not found practicable these wires are covered with false streamline covers of wood or metal. It is found that the reduction in resistance more than compensates for the additional weight involved in applying these false covers.

The resistance of the fuselages, radiators, engines, tail control surfaces, elevator rudder, aileron horns and all other elements is computed in detail, and account is also taken of the obliquity of these elements to the flow of the air. Such obliquity is found to exert an important influence on their action. For preliminary estimates, it is customary to determine the resistance of these elements for the position assumed by them at some speed intermediate to the low flying speed and to the high speed attainable with full power, and then to assume that the resistance of these elements is proportional to the square of the speed for speeds above and below the intermediate speeds selected. This is most handily done by assuming that the resistance of these elements is represented by a flat surface exposed normal to the wind, which would have the same resistance as the aggregate of these elements. This suppositious surface is what is referred to when we speak of the "surface of equivalent head resistance." In the example which I have chosen to illus-

Digitized by Google

trate, "the equivalent head resistance" is assumed to be 20 sq. ft., and the horsepower required to drive this head resistance through the air is indicated on the curve denoted head resistance horsepower. By compounding the ordinates of this curve with the ordinates of the plane's effective horsepower curve we derive the total effective horsepower required curve.

We have next to determine the total brake horsepower available in order to determine the performance of the airplane. To determine this curve, we must first know the full-throttle characteristic of the engines to be used. This characteristic is indicated in the example showing the brake horsepower available at different speeds.

The next thing to be determined, and the one having a most important influence on the performance of the airplane, is the propeller characteristic. To date the progress in propeller design has been far from satisfactory, and although good results have been obtained, the best results possible have seldom been approached. In the selection of the propeller, one of the first considerations is to determine what feature of performance is most important, for it is necessary to select the proper dimensions with a view to gaining the best results for the service intended. For instance, if high speed is of greatest importance, the propeller to be selected will differ materially from that which would be required if great climbing power is desired, because the greatest climbing power will be attained at a speed much lower than the maximum rate. Or, it may be a question of selecting a propeller which will give the greatest efficiency at cruising speed, and this propeller will usually differ from that selected in either of the preceding cases. In some cases it may be desirable to select a propeller which will give the best all-round performance rather than for a particular condition.

In seaplane work a problem arises which is not found in the land airplanes. This problem is that of obtaining the greatest reserve of power to overcome the resistance of the float system, because it is desirable to have the greatest possible reserve to accelerate rapidly on the water, so that the get-away may be made in rough water with the greatest possible rapidity, thereby reducing the punishment which the seaplane suffers under such conditions. For a heavily loaded seaplane this consideration may be of vital importance.

Digitized by Google

Efficiency of the Propeller

It must be understood that the efficiency of an airplane propeller is absolutely dependent upon its speed of advance through the air, as is also the power which the propeller absorbs in flight, the result being that even though the full throttle is used the engine cannot make its full revolutions until a good flying speed is attained, with the consequence that full power of the engine cannot be realized until flying speed is attained.

The efficiency of a propeller is dependent upon a function of the velocity and the number of revolutions and the diameter of the propeller represented by the fraction $\frac{V}{ND}$. The efficiency, the torque and the thrust, the horsepower absorbed and the horsepower delivered are functions of this quantity, in which velocity, the number of revolutions and the diameter must be expressed in the same units.

The influence of this factor is indicated on the propeller efficiency curve based on the values of the fraction $\frac{V}{ND}$. When this fraction equals 0.2 the efficiency of the propeller indicated in the example is only 37.5 per cent. The maximum efficiency is attained when the value of this fraction is 0.59, the maximum efficiency indicated in this case being 73.2 per cent.

In the example chosen I have used a Durand propeller No. 8, the characteristics of which have been determined by wind-tunnel tests, as given in report No. 14 of the proceedings of the National Advisory Committee for Aeronautics, 1914.

To derive the dimensions for this propeller I have assumed that it is desired to attain the best results at 80 miles per hr. with a Liberty engine operating at 1600 r.p.m. and developing 380 b.hp., as shown by the engine characteristic. In Professor Durand's report he has adopted Eifel's logarithmic chart, and I shall now indicate how the diameter of the propeller is determined.

On the chart at a speed of 80 miles per hr. erect an ordinate equal to 380 hp. taken from the scale on the left side of the chart. From the top of this ordinate next draw an oblique line parallel to the line indicating the speed, and draw this line of such a length and in such a direction as to represent 1600 r.p.m. on

Digitized by Google

the scale starting with the origin at 1200 r.p.m. From the extremity of this line next draw a line parallel to the line giving the diameter scale, and taking the distance from this point to its intersection with the propeller characteristic for the propeller No. 8 we find that this line intersects at the point *O*. Transferring the length of this line to the diameter scale and measuring in the direction in which it is necessary to draw this line to make it intersect with the propeller's characteristic, we

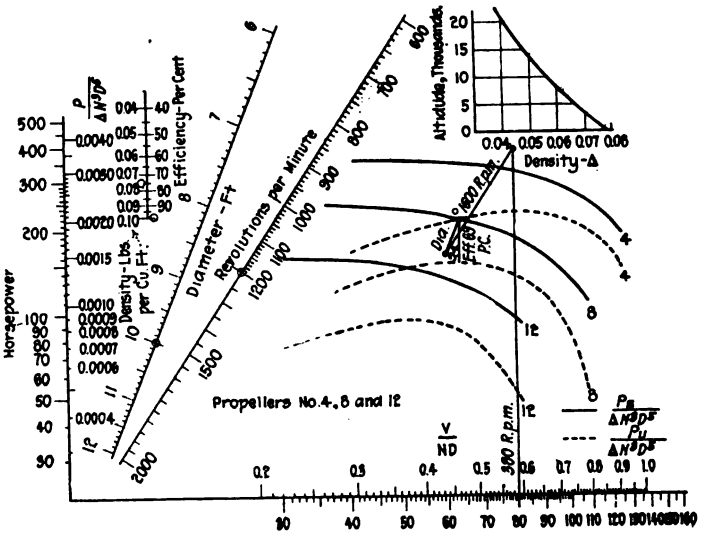


CHART FOR DETERMINING THE DIMENSIONS OF PROPELLERS

find that the proper diameter to use is 9.4 ft., indicating an efficiency of 69 per cent. By the use of this ingenious chart it is possible to select a proper diameter for a given set of conditions by a simple graphical solution.

The diameter now being determined, it is next necessary to determine the performance of the combined engine and propeller, and this is done as follows: On a transparent sheet of paper or tracing cloth a base line is drawn and, from any convenient point on this line, another is now drawn parallel to the scale of propeller diameters and a distance is laid off representing the diameter of the propeller on that scale. From the

Digitized by Google

extremity of this line a new line is drawn parallel to the scale of revolutions per minute, and on this line is indicated the revolutions per minute of the powerplant, using the scale of r.p.m. for this purpose. From each point representing the different revolutions vertical ordinates are now drawn, representing, according to the horsepower scale, the brake horsepower developed by the engine at these revolutions, and through the points so determined an engine brake horsepower line is drawn.

Next place this diagram on top of the logarithmic diagram of the propeller, placing the origin on the base line *A* on the base line of the logarithmic diagram with the point *A* at the speed at which it is desired to determine the brake horsepower available. The propeller efficiency, and from the latter the effective horsepower available, can now be determined.

This construction is based on the fact that the horsepower absorbed by the propeller and the horsepower delivered by the engine must agree. Thus, for example, placing the point *A* at a speed of 30 miles per hr. it is found that the brake horsepower curve of the diagram intersects the propeller characteristic and the engine characteristic at a point *B*, indicating that the engine will make 1500 r.p.m. and develop 355 b.hp. at this speed of advance.

By drawing a vertical line through this point of intersection of the two curves to the dotted characteristic of the same propeller, the effective horsepower developed by the propeller can be determined. This can also be determined by measuring the distance on the vertical line between the full line and dotted line representing the propeller characteristics. By transferring the length of this line to the scale of efficiency, the propeller efficiency can be determined.

In this manner the brake horsepower available and the effective horsepower available have been determined and are shown on the horsepower curves. It will be seen that at 30 miles per hr. the engine can turn the propeller at only 1500 r.p.m., developing 555 b.hp. Also, that at this speed the efficiency is only 35 per cent and only 124 e.hp. is available, although the engine is developing 355 b.hp.

Determining Plane Performance

Having now determined the effective horsepower available, we are ready to determine the performance of the

Digitized by Google

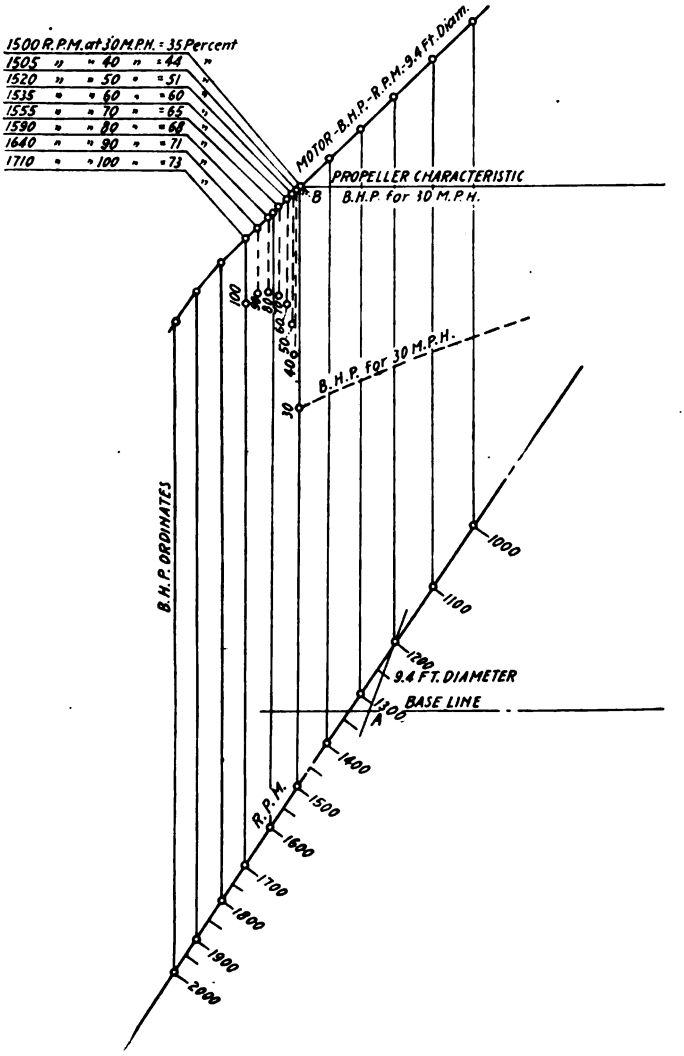


CHART FOR DETERMINING THE PERFORMANCE OF A LIBERTY ENGINE AND A DURAND NO. 8 PROPELLER

Digitized by Google

airplane. It will be noted that the lowest speed indicated in power flight is 58.5 miles per hr. Thus these two points of performance are determined.

The climbing power of the airplane with full power is determined by taking the difference of the effective horsepower required and that available at the particular speed at which the airplane is flown in the climb. This difference is greatest at the speed of 73 miles per hr. The climb is determined from the reserve effective horsepower available, which in this case is 76. Multiplying this effective horsepower by 33,000 and dividing by the weight of the airplane, assumed in the example to be 6500 lb., it is found that the initial climb should be 386 ft. per min.

Further inspection of the curves shows that the minimum horsepower is required at a speed of 62 miles per hr. It is at this speed that the airplanes should be flown to get the greatest endurance. If, however, it is desired to get the greatest range, the most favorable speed will be indicated by drawing a tangent from the origin to the effective horsepower required curve, as at this point the most favorable ratio is attained between velocity and horsepower required.

In the example this speed is found to be higher than the speed for minimum power and is about 73 miles per hr. It will be noted that the tangent to the curve substantially conforms to the curve over the range of speed from 70 to 76 miles per hr. If the endeavor is being made to cover the greatest possible distance, it would be desirable to select the higher of these two speeds. for the reason that at the higher speed the controls would be more effective; the flight would be steadier and would be accomplished in a shorter time.

As the airplane proceeds its weight will be reduced because of the consumption of fuel, and with a plane of heavy carrying capacity this reduction of fuel at the end of a long flight will appreciably reduce the load and thereby decrease the horsepower required for flight.

In the example chosen, I have indicated the horsepower required when all the fuel is used up, assuming a weight at this time of 4500 lb. In this condition the most efficient speed will again be indicated by a tangent to the origin, and in the example this speed is appreciably lower than that indicated for the full load condition,

Digitized by Google

being anywhere from 55 to 60 miles per hr. At intermediate stages intermediate speeds will be found the best for the greatest range. This, therefore, indicates that in planning a long-distance flight due account should be given to this effect, as the radius of flight will be appreciably increased if proper account is taken of the influence of change in weight. To be exact, the tangent should not be drawn to the effective horsepower required curve, but to a set of curves which can be derived from these curves indicating the fuel consumption at different speeds and at different loads. The determination of the fuel consumption curves is a simple matter, but it would take more time and space than I consider it desirable to give in this paper. I can state, however, that the favorable speeds for long-distance cruising are not appreciably affected by using these fuel consumption curves in preference to the effective horsepower required curves.

The computations made in deriving the curves shown have been based on the Liberty engine, using straight drive. If it were possible to have available the same power with the geared-down propeller, it would be possible to greatly improve the propeller efficiency and thereby to improve the performance of the airplane indicated in the example: It is unfortunate that the geared-down engine is not available for general use, as the performance of practically every plane I know of using this engine in our country would be materially improved by its use. An inspection of the $\frac{V}{ND}$ efficiency plot will make this clear. I also consider it unfortunate that in the development of the geared-down Liberty engines which have been produced, advantage has not been taken of the possibility of locating the propeller more centrally in relation to the engine group, because of the advantages which would be gained in streamlining. This engine is extremely awkward to streamline in its present form.

Design of Seaplane Floats

I will now proceed to the consideration of some of the elements of design of seaplane floats. The requirements of seaplane floats, because of the nature of their use, are necessarily conflicting, and the best that can be done is to make a compromise, bearing these in mind.

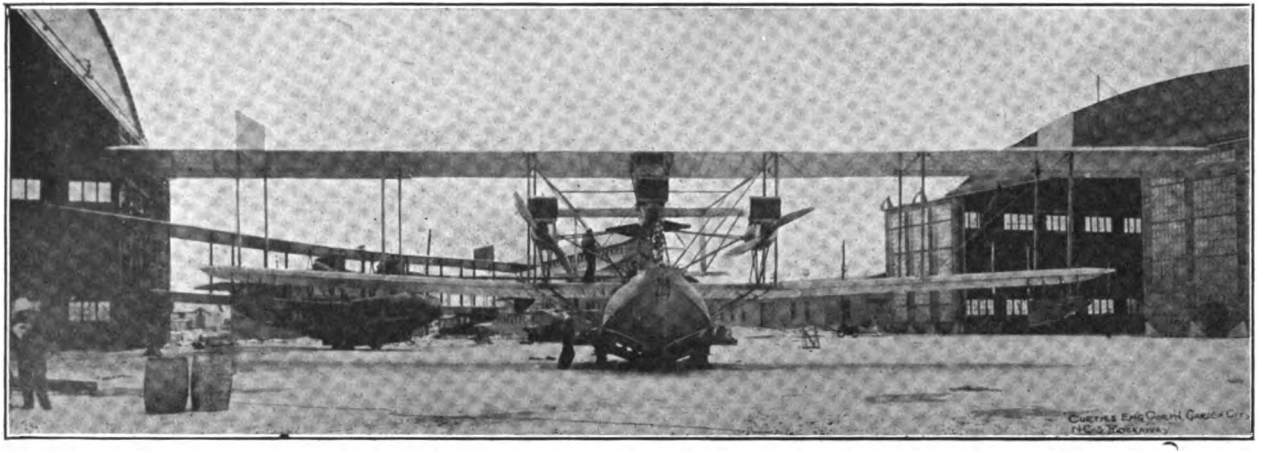
Digitized by Google

The first requirement of a float is that it shall be seaworthy. This requires that the form shall be properly proportioned to provide good initial stability and a reserve of buoyancy. This is necessary to obtain a reserve of stability, as the seaplane must float without capsizing in a sea-way and in strong winds. This requirement in itself conflicts with airworthiness and lightness and with the adoption of the best streamline form, which otherwise would be, in general, a form similar to a dirigible. It must be strong, but this naturally conflicts with lightness. It must also have good planing qualities, and this requirement conflicts with streamline form. Airworthiness requires that it should have the minimum resistance and interfere in the least possible degree with the other characteristics of the seaplane.

In order to develop the best form of hull, the Navy Department began experiments at the Washington model basin late in 1911. These experiments were initiated by Capt. W. I. Chambers, U. S. N., with a view to the use of hydroplane blades, such as had been used by Forlanini, and to improving the planing qualities of the then existing types of floats. At that time the most successful float was that constructed by Glenn H. Curtiss, having a simple box section and a sled-form profile. At the same time Burgess had developed twin floats having a single step, which had also proved successful.

One of the earliest experiments at the model basin was an attempt to reduce the wetted surface to a minimum by the use of a semi-circular section in the form of a half-cylinder whose ends were pointed like a projectile to reduce the air and water resistance. It was fortunate that this model was tried among the first, for its trials at once showed up a factor which later was discovered to be of the greatest importance, this factor being suction, due to downward curved surfaces when exposed to the contact of water at high speeds. It was at once realized that in the test of the floats due allowance should be made to represent the change in load carried by the float as the speed of the seaplane increased and the lift of the wings became an important factor, and all runs at the model basin had been made taking account of this and determining for each particular speed the "corresponding displacement" of the float. This was originally done by counterweighting the float so that the

Digitized by Google



THE NC-3 SEAPLANE WHICH IS A COMPROMISE BETWEEN THE HYDROPLANE AND FLYING BOAT TYPES

Digitized by Google

weight resting on the water represented that which would be the case taking into account the auxiliary lifting power of the wings. In the latest form of apparatus for testing at the basin this compensation is automatically made by the use of an inclined vane submerged in the model basin, which, by means of a system of pulleys, exerts a lifting power which is proportional to the lifting power of the wings at the speed at which the test is run.

In the tests with the semi-cylindrical model above referred to, it was found, as anticipated, that the resistance at low and moderate speeds was less than that experienced with other models, but as one-half of the speed for the get-away was approached, and therefore the float carried only three-quarters of the original load, it was found that the resistance of this model instead of decreasing, increased; and that the model, instead of planing, as was expected, settled into the water and, finally, at the get-away speed, with no weight being carried by the float but the float just in contact with the water, the influence of suction was so great that this model, instead of skimming the surface, proceeded to envelope itself in water and was drawn down so sharply by suction that its deck was flush with the surface of the water in the tank and great sheets of spray were lifted clear of the surface of the model basin.

As the work progressed the models of every known successful type of float were tried in the model basin, and data were collected as to the performance of these models. At the same time many experimental models were tried, and when these showed improvement over existing types, full-sized floats were constructed and tried out in actual flight. From these trials it was found that the conditions indicated in the model basin were duplicated in practice with full size, and it was seen that the model basin tests formed a means of predicting the performance of full-sized floats.

The steps of the Burgess floats were ventilated, and an investigation of this feature showed the value of ventilation for the step-type floats then in use.

All sorts of bow forms were tried and were shown to have very little influence on performance. The use of one, two, three and four steps was tried, and the indications were that there was little, if any, advantage to be gained by the use of more than two.

The introduction of the V-bottom showed promise of improvement, but it was early found that a V-bottom

Digitized by Google

at the bow was invariably associated with large quantities of spray which would flow over the planes, and also, in a cross-wind would make the navigation of the seaplanes very uncomfortable. It was found by making the lines hollow at the bow that this spray could be held down close to the water, and in some later designs this hollowness was also introduced at the step, apparently with beneficial results. After much experimenting it finally became apparent that the best form of hull was that embodying the single ventilated step, in which the after bottom rose at an angle of approximately 8 deg. to the bottom just forward of the step. The reasons for this are about as follows: With this type of float sufficient buoyancy can be provided abaft the step to eliminate the necessity of tail floats for stability. It was also found that by ventilating the step the water flowing under the forward bottom flowed over the step in the form of an inverted waterfall and that the contact of this inverted stream moved further aft as the speed increased and generally passed clear of the tail of the float just before planing was attained. At this point maximum resistance was encountered. After this point was passed the float proceeded to plane on the forward step, and because of the raised position of the tail of the float, it was then possible to vary the trim of the plane and change the angle of attack without again bringing the tail of the float into the water. Then progressively as the speed increased to flying speed the planing power of the portion forward of the step increased rapidly and the amount of wetted surface exposed to the action of the water was rapidly reduced, and the resistance of the float decreased, until finally at the get-away the water resistance of the float was eliminated.

The best results are obtained where the bottom of the float just forward of the step is substantially parallel to the axis of the seaplane. This portion of the bottom should have no curvature for a distance of several feet forward of the step.

Attempts were made to curve up the portion abaft the step with a view to producing a better streamline form for the hull, but this curvature was invariably found to produce suction, retard planing, and in many cases to augment the resistance of the float to such a degree as to require an excessive reserve of horsepower in order to get away. There was one case where a flying boat was built with very moderate curvature abaft the step, but

Digitized by Google

on account of this curvature in the tail was unable to leave the water with a single passenger. Even though it could get up to a speed where the step itself was clear of the water, the tail would still drag and could not be drawn out of the water. By slightly modifying the tail of the float so that the lines abaft the step were straight, this same flying boat with the same powerplant was able to get off the water with a pilot and passenger.

One of the earliest floats tried at the model basin and built in full size was a twin float having a sharp V-bottom. The lines of this float conformed to the lines of a successful gunboat, and it was very pretty and clean in its action, but due to the influence of the curvature of the buttock lines at the stern, suction was present in this model and an airplane fitted with these floats, although able to get away with a pilot, was unable to get away with a pilot and passenger, there being insufficient reserve power to get over the hump.

Until very recently it was considered that so many inches of beam were required for every 100 lb. of weight carried by the float in order to attain planing, and this criterion has led to the adoption of the great beam found in the F-5 and H-16 and HS-2 models. But experiments with floats suited to carry 1000 lb. each indicated that this model was remarkably satisfactory. The attempt was therefore made to enlarge this model in geometrical proportion to a 2000-lb. float, and the model basin results indicated that this could be satisfactorily done. Another model was made of a 2000-lb. float and behaved satisfactorily. This same model was expanded to a 6000-lb. float, which behaved even better than the original. The lines of the N-9 float, which has proved successful in our training program, were developed from the original 1000-lb. float, although this float had less beam than the original full-size float which was unsuccessful. As a result of these trials, I now consider it to be conclusively established that once a satisfactory float is developed for carrying a definite load under given conditions, the same design can be used for larger loads by merely expanding the original lines in the ratio of the cube root of the displacement ratios.

In the design of the float for the NC-1 this principle was used and the model tested in the model basin, although only one-twelfth full size, gave data which indicated satisfactory performance. These data have been closely verified by the actual performance of the NC-1,

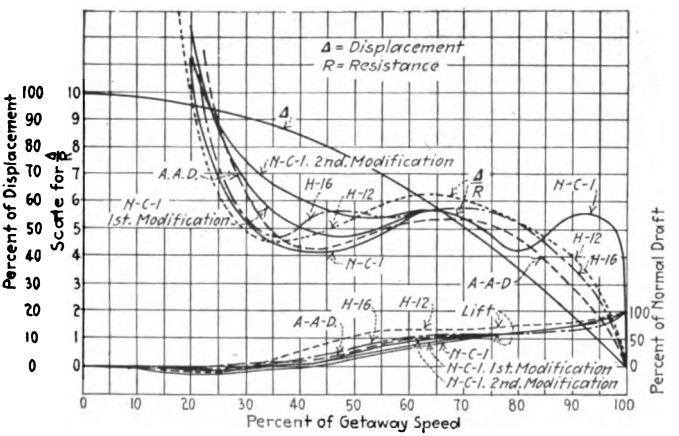
Digitized by Google

though many designers were skeptical that this float could handle its load on so narrow a beam. This is no greater than that used in the F-5; the F-5 carries a load of only 13,000 as against over 22,000 lb. carried by the NC-1.

Results of Model Basin Tests Compared

The dimensions of the floats and the seaplanes they represented were so different that to get a comparison it has been necessary to plot these results on non-dimensional scales. It will therefore be noted that the displacement of the hull is plotted as a percentage of the total displacement based on a percentage of the get-away speed. The resistance of these floats is indicated by a plot of the ratio of the displacement to the resistance; also, based on the percentage of the get-away speed.

Based on the plot of a successful H-12 boat, I have plotted the resistance and the horsepower required to overcome this resistance for the sample seaplane, the horsepower curves of which I have already explained, and I shall return to those plots in a few minutes. Before doing so, however, I wish to invite your attention to the plots of models of the original NC-1 and its two modifications. You will note that the resistance of the original boat was nearly one-quarter of the displacement at 40



Results of Tests at Model Basin on a Number of Seaplane Floats

Digitized by Google

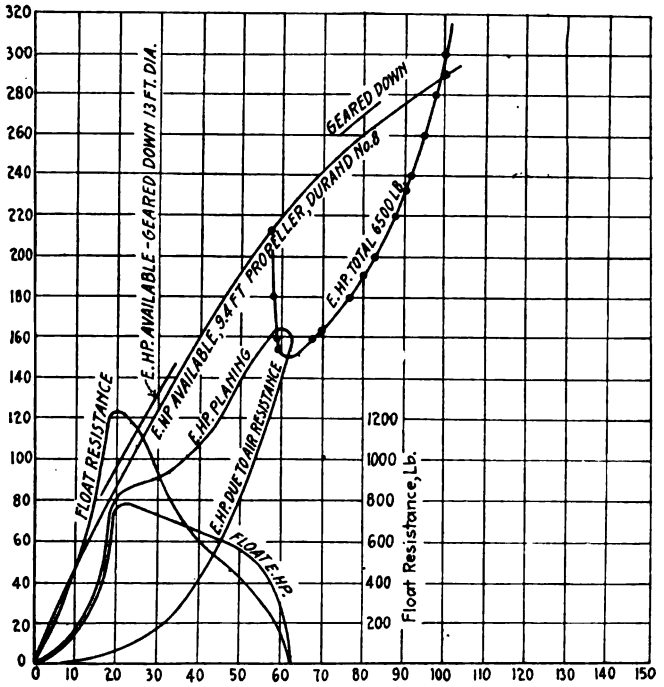
per cent of the get-away speed; that the resistance of the first modified form was reduced to nearly one-fifth of the displacement at about 47 per cent of the get-away speed, and the resistance of last modification was between one-fifth and one-sixth of the displacement at about 52 per cent of the get-away speed. Also, the displacement in the latter case is less than in the preceding cases.

This change was brought about as follows: The original form of float had two steps, with curvature in the middle step and a rank up-curvature in the rear step. In the first modification the rear step was straightened, and the later type had straight lines for the bottom abaft the first step. It will readily be seen that the first modification was an improvement over the original, and the second modification was a still greater improvement. These models represent the model of the NC-1, and there is no doubt in my mind that if the original model had been used this seaplane could not have got off the water. Further, the influence of the curved portion of the tail of the float would have been so great as to cause the machine to squat so badly that the tail surfaces would have been caught in the stream of water rising from the tail of the float.

Let us now return to the horsepower curves. It will be noted that the resistance of this seaplane float reaches a maximum at a speed of 20 miles per hr., which speed corresponds to the point at which planing begins, and that there is a secondary hump at a speed of 40 miles per hr. The get-away speed is assumed as 62 miles per hr. The horsepower curve has been directly derived from the resistance of the float, and this horsepower must be compounded with that of the airplane progressing through the air. The horsepower required for this purpose is determined by taking the horsepower of the airplane at 62 miles per hr., which in this case is 150 e.hp., and noting that the horsepower for the wings and head resistance is proportional to the cube of the speed. We thus derive the curve of the total air e.hp. required for the seaplane, which must be compounded with the horsepower required for the float, thus giving us a total horsepower curve for the seaplane for speeds below the get-away speed, that is, while still in the water.

From an inspection of the horsepower curves, it will be seen that the maximum horsepower for the float is required at a speed of about 23 miles per hr., and that this,

Digitized by Google



SEAPLANE HORSEPOWER CURVES AFLOAT AND FLYING

compounded with the horsepower due to air resistance, requires 88 hp. at this speed.

The horsepower for planing is very little exceeded by the horsepower available, so that it would take a relatively long time to pass through the planing condition; but, after this point is passed, the seaplane should accelerate rapidly because the reserve of horsepower available rapidly increases up to the get-away speed.

There is a secondary hump in the horsepower curve at 60 miles per hr. just before the get-away is attained, but this secondary hump is of little importance as there is an ample reserve of horsepower at this point.

As a matter of interest, I have investigated the improvement in performance which could be expected if a geared-down engine were used, assuming a ratio of 0.6; that is, the propeller turning at 0.6 of the revolutions of

Digitized by Google

the engine. With this gear ratio a propeller of 13 ft. in diameter is indicated. Such a propeller at a speed of 80 miles per hr. would show an efficiency of 73 per cent as against 69 per cent for the 9-ft. diameter propeller. This gain of 4 per cent at 80 miles per hr. would increase the climb by more than 11 per cent. It would have little effect on the speed, as the horsepower curve is very steep in this region. The improvement in efficiency at 20 miles per hr., although only 6 per cent would mean an increase of 200 per cent in the reserve of horsepower to get over the hump in the horsepower curve at that speed. You will therefore see why in Naval work the use of the geared-down propeller offers considerable advantage. The substitution of the geared-down Liberty for the straight-drive Liberty engines in the F-5 changes the top speed of this seaplane from 90 to 100 miles per hr. and makes the get-away of this seaplane certain and rapid under all conditions, whereas the straight-drive propellers were only able to get this boat away with great difficulty in a calm.

The V-Bottom versus the Flat

Experiments have recently been made at the model basin on a series of models having different angles of V-bottom from the flat bottom up to a 20-deg. V, and it is found that from a resistance point of view there is very little difference in the performance of the four models tried. So far as any advantage is shown, the deep-angle V has slightly the best of the argument. From a service point of view the deep V-bottom has many advantages; among them its remarkable shock-absorbing properties in taking care of bad landings, or in getting away and landing on a rough sea. The V-bottom also permits landing across the wind without serious retardation and without danger of capsizing sideways. This type of hull appears to absorb the shock by penetration and reduces the loads imposed on the bottom planking and on the framing supporting this. Due to this feature there is no need of carrying shock absorbers between the floats and the rest of the plane structure, and the lightest possible construction can be adopted.

The first hulls built in this country had an elaborate framework of ribs and longitudinals supporting the bottom planking, which afforded a regular network having

Digitized by Google

hundreds of intersections requiring fastening, the fastenings themselves weakening the frames and the longitudinals at the point where the frames carried concentrated loads on small areas of side grain. This type of construction was unnecessarily heavy and costly and was abandoned early in the construction of pontoons of Navy design in favor of the longitudinal system of support.

In the longitudinal system of support the inner ply of planking is run athwartship and thereby constitutes a continuous system of ribs. This system is further reinforced by the outer planking run 45 deg. to the keel, which also acts as a continuous system of ribs, and these two systems transmit the water pressure as a distributed loading to the longitudinal members, which do not have their strength robbed by a series of notches. The longitudinals are arranged so that they collect the distributed load and concentrate it at points of support in athwartship bulkheads and these bulkheads in turn distribute the load to the keel, to the chine stringers, and to the deck planking. The keel itself is usually associated with a center longitudinal truss. Through these members the load is finally distributed to struts or directly to the wing structure.

On a large scale this system is adopted in the construction of the hull of the NC-1 which, although it embodies other features than those necessary to support the bottom planking, weighs only 2600 lb. while it carries a load of 22,000 lb. This hull has demonstrated ample strength in landing on and getting off an 8-ft. cross sea in practically dead air, where the landing and get-away were both made under the hardest conditions.

A controversy has existed for years as to the merits of the single float as compared with the twin float, but, based on the experience of our Navy with examples of both types, I believe that the central float with wing-tip balancing floats is decidedly the better arrangement. In the central float system the loads can be concentrated on the point of support, whereas in the twin-float system the loads are usually concentrated in the center of the span and the wing structure has to be utilized to gain the necessary stiffness and necessarily has to be made heavier. In the center-float type if a single propeller is used it is located above the float and protected from the water, whereas in the twin-float type such propeller nec-

Digitized by Google

essarily swings over the gap between the floats, which subjects it to punishment by spray and broken water. In landing a twin-float seaplane, unless both floats arrive at the same time, the second float invariably strikes harder than the first, being slammed down on the water. Due to the greater lateral stiffness of the twin-float system, when getting off rough water the seaplane is forced to conform in its attitude to the form of the surface and wracks and lurches violently sideways unless going directly across the crest of the sea. In maneuvering in the air, also, the separation of the twin floats adds considerably to the inertia about the longitudinal axis and makes the action of the ailerons less effective. With twin floats, when taxi-ing across a strong side wind the lee float must have at least 100 per cent reserve buoyancy, and this leads to greater weight than is necessary with the single center-float providing the same stability.

Types of Navy Planes

As above referred to, the principal types of service planes used by the Navy were the HS-2, H-16 and F-5.

The HS-2 was developed from an original twin-motored seaplane designed for the Army, which, however, did not prove successful. It was originally intended to be used with two 100-hp. engines. Later, when the Navy took hold of it, the Curtiss VX3, a 200-hp. engine, was used, and this seaplane gave a fairly satisfactory performance with this powerplant. At about the same time the Liberty engine became available, and as soon as it was installed it was found that this performance was very much improved and this seaplane was capable of flying at a total weight of about 5900 lb. On this basis it was then attempted to convert it into a military machine by providing the necessary guns, bombs and other equipment. After everything had been added, it was found impracticable to carry the military load desired on a limit of 5900 lb. total weight. The expedient was therefore adopted of adding wing surface, and the original HS-1 thus became the HS-2, capable of carrying a load of 6500 lb. with practically no reduction in full speed and with considerable increase in climbing power. Many forced landings have been made at sea; some due to powerplant difficulties, such as stoppage of fuel supply, or failure of the engine or propeller, and sometimes due to head winds forcing a landing on a return trip on

Digitized by Google

account of exhaustion of fuel. Although many of these landings were made under bad weather conditions and in rough seas, in nearly ever case landings were accomplished without serious damage to the hull.

The general arrangement of this seaplane is indicated in the illustration. The pilot and assistant pilot are seated in a cockpit just forward of the wings, from which point they have a good view for the operating of the seaplane. A radio outfit is provided just forward of the pilot. A gunner's cockpit is fitted in the bow, and this cockpit is provided with a gun ring and Lewis gun. This gunner has a very good range of fire, particularly ahead and down and on either beam; also upward and to the rear above the planes. But there are no means of firing abaft the beam, and the boat is unprotected against attack from the rear. In the gunner's cockpit are also fitted the bomb pulls and the sight for dropping the bombs, which are located under the wings just clear of the hull. On account of its undefended condition against attack from the rear, this seaplane was not used in sectors where it would be exposed to attacks by enemy aircraft, but there were many places abroad—and, of course, in this country—where no such attack was probable and where it proved particularly useful in submarine patrol and convoy work. This seaplane is also used for instruction purposes as an advance step toward handling the regular twin-motored seaplanes. The HS-2 is provided with a single Liberty engine and a pusher propeller, and has very satisfactory air maneuvering qualities.

The H-16, as you will see, was a twin-engined seaplane with a flying-boat hull, using tractor propellers. The pilot and observer are seated in a cockpit about half-way between the bow and the wings, where they have an excellent view. The H-16 was also fitted with a gunner's cockpit the same as the HS-2. In addition, a wireless operator was carried inside the hull just forward of the wings and back of the pilots. Abaft the wings an additional gun ring was fitted covering the arc of fire above and between the wings and the tail controls and to take care of the region to the rear and below the tail controls; gun mounts were also fitted, swinging on brackets through side doors in the hull. The bomb gear was operated from the forward gunner's cockpit and four bombs were carried, two under either wing. This type of boat proved very serviceable, and was a substantial

Digitized by Google

copy of the same type of boat built in this country for England, differing only in minor details from those supplied to England. This boat was really a successor to the H-12, which was very similar, except that the hull of the H-12 was more like that of the HS-2 both in construction and in the form of the planing fins.

As you will note, the F-5 is very similar to the H-16, being approximately 10 per cent larger than the H-16. In addition to this increase in dimensions, which was made to afford a greater military load, it will be noted that this seaplane has balanced wing-tip ailerons and also a balanced rudder. The hull form is practically identical with that of the H-16. The principal data of all three of these boats will be found in the Appendix.

A little over a year ago the Navy Department decided to build a large seaplane equipped with three Liberty engines and, after consultation, a contract was entered into with the Curtiss Aeroplane & Motor Corporation and a design was developed, under the supervision of representatives of the Navy Department, first at the Austin Street plant of the Curtiss corporation in Buffalo and later at the Garden City plant of that company. As a result, the NC-1 was developed and built and has recently undergone trials at Rockaway Beach.

It will be noted from the illustration that this seaplane is neither a hydroplane nor a flying boat. It may be considered a compromise between these two types. The three engines are arranged as tractors in separate nacelles placed between the wings, and the pilot and assistant pilot are located in a cockpit just abaft the center motor. One gunner's cockpit is located on top of the center plane, while another is placed in the bow. The tail is of the biplane type and supported by hollow spars in an inverted pyramidal form of structure resting on the stern post of the hull. The pilot and observer have an entirely satisfactory view for general maneuvering and for landing and get-away. It was contemplated that additional gunners would be placed in the after portion of the hull with guns mounted on brackets so that they could cover the arc of fire from the beam to the stern and downward; also that this seaplane would carry a number of bombs, together with a non-recoil gun of large calibre at the bow. Three more of this type are under construction, and advantage is being taken of the opportunity to make a number of changes which it is

Digitized by Google

believed will improve performance over that of the original.

Future Developments

I have been asked to incorporate in this paper some remarks on the future developments for the Navy, but as these more properly come under the subject of operations of the Navy, on which subject we are to hear from Commander Towers, I shall limit my comments to the statement that the Navy Department fully appreciates the desirability of experimenting with a view to improving existing types and the development of new types of seaplanes and airplanes, directed to the solution of those problems which have arisen in the war and, more particularly, to the development of seaplanes or airplanes for operation with the fleet. This development, as I pointed out at the beginning of this paper, was naturally set aside because at the time of the entry of the United States into the war the lines on which development was most badly needed were already pretty definitely determined and there was almost no need of airplanes for operation with the fleet. I believe that much larger seaplanes are possible and will probably be found useful for Naval work, and development on these lines may reasonably be expected.

This paper has already reached too great a length for me to enter into the subject of structural design, which is a very broad subject in itself. It is a matter of interest to know that so far as this branch of aeronautic engineering is concerned, very satisfactory progress has been and is being made, and along these lines some of the greatest improvements in the near future may be expected. So far as aerodynamic engineering is concerned, wind-tunnel experiments and full-sized experiments have now brought this branch to a very satisfactory state, so that the performance of a new design can be very definitely determined, even before construction is begun. So far as the engineering features of float design are concerned, I believe important progress has been made through the demonstration that model basin data can be accurately applied to full-sized design.

Appendix

The tables appended give the calculations for the performance curves of a seaplane with a biplane arrange-

Digitized by Google

ment of RAF 6 wings and a head resistance of 20 sq. ft. In these calculations the following formulas were used:

$$T = W \div \frac{K_y}{K_x} V^2 = \frac{W}{K_y S} EHP = \frac{TV}{375}$$

W = Weight in pounds
T = Thrust in pounds
V = Velocity in miles per hour
S = Wing surface in square feet
K_x = Drift factor for biplane arrangement
K_y = Lift factor for biplane arrangement

$EHP_h = \frac{K_x S V^3}{375}$ and is independent of the angle of attack

$K_x S = 0.06$ and $\frac{K_x S}{375} = 0.00016$

V	V^3	EHP_h
10	1,000	0.16
20	8,000	1.28
30	27,000	4.32
40	64,000	10.24
50	125,000	20.00
60	216,000	34.60
70	343,000	55.00
80	572,000	82.00
90	729,000	116.50
100	1,000,000	160.00
120	1,728,000	276.00

$$\frac{EHP_1}{EHP_2} = \left(\frac{W_1}{W_2}\right)^{\frac{3}{2}} \frac{V_1}{V_2} = \left(\frac{W_1}{W_2}\right)^{\frac{1}{2}}$$

$W_1 = 6500$ $\quad \frac{W_1}{W_2} = 1.442$
$W_2 = 4500$

$$\left(\frac{W_1}{W_2}\right)^{\frac{1}{2}} = 1.2 \quad \left(\frac{W_1}{W_2}\right)^{\frac{3}{2}} = 1.73$$

L	EHP_1	V_1	EHP_2	V_2
0	404.0	147.0	234.0	122.5
2	148.5	104.5	86.0	87.0
4	110.0	87.0	68.5	72.5
6	106.7	77.5	61.5	64.5
8	108.0	70.5	62.4	58.8
10	108.2	65.7	62.5	54.8
12	112.2	61.7	65.0	51.5
14	132.0	59.5	76.3	49.6
16	181.0	58.5	104.6	48.8

The float EHP for an H-12 seaplane weighing 6500 lb. and having a get-away speed of 62 miles per hr. is given on page 369 for varying percentages of the get-away speed.

THE DISCUSSION

GROVER C. LOENING:—An interesting point that appears from the tables is that in the case of the HS-2 for

Digitized by Google

Angle of attack, deg.	$K_x \times 10{,}000$	$K_y \times 10{,}000$	K_y/K_x	W	T	K_yS	V^2	V	TV	*EHP* Planes
0	0.62	4.3	6.3	6,500	1,030	0.301	21,600	147.0	151,300	404.0
2	0.65	8.5	12.2	6,500	532	0.595	10,900	104.5	55,700	148.5
4	0.88	12.3	13.7	6,500	474	0.861	7,550	87.0	41,200	110.0
6	1.20	15.5	12.6	6,500	516	1.085	5,990	77.5	40,000	106.7
8	1.65	18.7	11.3	6,500	575	1.309	4,960	70.5	40,500	108.0
10	2.06	21.6	10.5	6,500	618	1.512	4,300	65.7	40,600	108.2
12	2.55	24.4	9.5	6,500	684	1.708	3,800	61.7	42,200	112.2
14	3.30	26.4	7.8	6,500	833	1.848	3,520	59.5	49,500	132.0
16	4.85	27.3	5.6	6,500	1,160	1.911	3,400	58.5	67,900	181.0

Digitized by Google

example the machine in flight weighs something like 18 lb. per hp. and yet with this high load has a high speed of 91 m.p.h. An equally high efficiency is true of the NC-1 and indicates quite contrary to general belief that the aerodynamic efficiency of the U. S. Navy flying boat design is every bit as good as the fast land scouts, based on the criterion of pounds per horsepower. What is true of the small machine in increasing its performance by the refinement of design should be equally true of a large machine like the NC-1, and it would be interesting to have some information on the possible increase in load carrying and speed merely by eliminating many of the struts and wires still present in this type of craft. The paper presents briefly the usual accepted comparisons of the monoplane, biplane and triplane, with the indication that the biplane and triplane, are necessary for large lifting power and in large size due to the structural difficulties of monoplane types, even admitting their higher efficiency. From work already done on the monoplane type with rigid bracing, I do not agree with this point of view and feel that study and effort applied to the large monoplane would give some astonishing results in the improvement of speed range. Neither have I been able to find any greater structural limitations to the size of monoplanes than are found in other types of machines.

CAPT. W. I. CHAMBERS:—As to the most serviceable seaplane type at present, I can conceive of the serviceability of the following general outline: (*a*) One middle float entirely enclosed, without cockpits, machinery or cargo capacity; (*b*) a short middle fuselage located above the middle float, with engine, pusher propeller, cargo space and forward gun mount; (*c*) two wing fuselages, forming supports for the tail, *a la Caproni*, each with engine tractor propeller and rear gun mounts; (*d*) two smaller wing floats for balancing purposes, not at the wing tips, but located under the tractor propellers of the wing fuselages; (*e*) the tail planes comparatively near the main ones and rigged so that they may be utilized, in a fixed position, to afford inherent stability on long steady flights and yet be capable of mobility in response to any demands for quick maneuvering. While I do not suggest any finality as to model or type of either powerplant or rig of the planes, I do not hesitate to predict, however, that future modification and

Digitized by Google

Per cent of Get-away Speed	*V*	Δ, per cent	Δ, lb.	Δ/R	*R*	*RV*	*EHP*
10	6.2	99.00	6,430				
20	12.4	95.70	6,220	9.80	635	7,880	21.0
30	18.6	91.00	5,910	4.90	1,205	22,400	59.8
40	24.8	84.00	5,460	4.65	1,172	29,100	77.7
50	31.0	75.00	4,870	5.40	903	27,100	72.3
60	37.2	64.00	4,150	6.15	675	25,100	67.0
70	43.4	51.00	3,310	6.10	543	23,600	63.0
80	49.6	36.00	2,340	5.30	442	21,800	58.2
90	55.8	19.00	1,235	4.00	309	17,300	46.2
100	62.0	0.00	0				

DATA ON DIFFERENT TYPES OF FLYING BOATS

	HS-2-L	H-16	F5-L	NC-1
Weight, fully loaded, lb.	6,432	10,900	13,000	22,000
Useful load, lb.	2,132	3,500	4,750	7,750
Maximum speed, miles per hr.	91	95	87	81[2]
Minimum speed, miles per hr.	55	56	57	61[3]
Initial climb, ft.	2,500 to 3,000 in 10 min.	3,000 in 10 min.	2,625 in 10 min.	1,050[4] in 5 min.
Over all span, ft.-in.	74 0 19/32	95 0 13/16	103 9 1/4	126 0
Over all length, ft.-in.	38 5 15/16	46 1 15/32	49 3 11/16	68 2 29/32
Over all height, ft.-in.	14 7 1/4	17 8 5/8	18 9 1/4	24 6
Chord, ft.-in.	6 3 5/32	7 0 49/64	8 0	12 0
Wing area, sq. ft.	803	1,164	1,397	2,380
Hull length, ft.-in.	34 3	42 7	....	44 7

[2]Carrying a load of 21,560 lb.
[3]Carrying a load of 21,569 lb.
[4]At a speed of 67 m.p.h. with a load of 21,318 lb.

Digitized by Google

improvement will depend more upon further improvement of the powerplant than on any other factor. Great improvements in this part of the aircraft are due, and each decisive step will result in a modification of airplane types for each specific purpose.

ORVILLE WRIGHT:—Commander Richardson's figures for the performance of propellers are based on tables derived from experiments with models. The trouble with tables of this kind comes from the fact that it is most difficult to determine the exact value of each of the factors which play a part in the propeller's efficiency. The tests are made with several variable factors, so that the measurements secured really show the result of the sum of these variables. The exact value of each one is not determined. I am of the opinion that much closer calculations can be had from a theoretical consideration of the reactions that must take place in a propeller. Commander Richardson finds that a propeller 9.4 ft. in diameter, driven by a Liberty engine, turning at 1600 r.p.m. and developing 380 b.hp., in traveling forward at a speed of 80 miles per hr., would have an efficiency of 69 per cent, or a loss of only 31 per cent. I believe it can be shown that the loss from slip alone, without considering any of the other losses, which also would be great, would be more than the amount he has found.

When the thrust is known the slip can be determined easily, because slip is merely the acceleration imparted to a mass of air by the impact of the propeller blades. Slip, therefore, must be equal to $V = \sqrt{2gh}$, in which V is the velocity; g, gravity or 32.17 ft. per sec.; h, head or pressure. Air at sea level may be considered as weighing 0.0762 lb. per cu. ft. or 13.123 cu. ft. of air weighs 1 lb. Hence a pressure of 1 lb. per sq. ft. would accelerate air at sea level to velocity equal to

$$\sqrt{2 \times 32.17 \times 13.123} \text{ ft. per sec.}$$

But it is well known that the rate of acceleration is directly proportional to the force and inversely proportional to the mass. Therefore acceleration will be proportional to the pressure divided by the volume of air. The pressure of 1 lb. per sq. ft. will accelerate 844 cu. ft. of air to a velocity of 1 ft. per sec. or 1 cu. ft. of air to 844 ft. per sec. The acceleration imparted to any other number of cubic feet of air can be expressed by the formula

$$\text{Acceleration} = \frac{844 \times \text{pressure in lb. per sq. ft.}}{\text{Cu. ft. of air acted on}}$$

Digitized by Google

The number of cubic feet of air acted on per square foot of disk area of a propeller is equal to the distance the propeller moves forward plus the acceleration or slip of the air acted on. Therefore

$$\text{Slip} = \frac{844 \times \text{thrust in lb. per sq. ft. of disk area}}{\text{Advance in ft.} + \text{slip in ft.}}$$

If the propeller considered by Commander Richardson had an efficiency of 69 per cent at 80 miles per hr. it would have a thrust of 1229 lb. Therefore the thrust would be 17.72 lb. per sq. ft. of disk area. In the formula for slip just given, substituting 17.72 for the thrust in lb. per sq. ft. of disk area, and 117.28 for the advance, we find the slip equals 76.96 ft., a loss of 39.62 per cent. It is therefore evident that it would be impossible to secure an efficiency of 69 per cent with any propeller of 9.4-ft. diameter consuming 380 hp. while advancing 80 miles per hr. I have made a rough calculation of the performance such a propeller should give, based upon the propeller being considered merely as airfoils traveling in a spiral course. A propeller 9.4 ft. in diameter working under the conditions stated would have a thrust of approximately 930 lb.; the slip would amount to 35 per cent of the total amount of air the propeller traveled through, and the efficiency of the angle of advance would be 80 per cent. The total efficiency would therefore be 0.65 x 0.80 or 52 per cent.

Commander Richardson uses a method of calculating the rate of climb of an airplane which seems of doubtful value. He makes no allowance, so far as I can see, for the extra loss in efficiency of a propeller when climbing. The thrust in climbing must be approximately equal to the thrust when flying at the same speed on a horizontal course plus the total weight of the machine multiplied by the sine of the angle of climb. It is apparent that if the machine were to climb in a vertical course the propeller thrust would necessarily have to be equal to the entire load of the machine. On an inclined course the propeller would have to bear a proportion of the entire load plus the thrust necessary to give the machine the desired speed. When climbing, the propeller efficiency is especially low in small-diameter propellers, because on account of the extra load imposed, the slip becomes excessive.

COMMANDER RICHARDSON:—A great amount of theoretical work has been done on propellers, taking it from

Digitized by Google

all points of view, but in my opinion none of these methods of analysis is as satisfactory as the wind-tunnel methods, because even the theoretical investigations require the use of coefficients which must be developed from experience or practice. And I believe that when a propeller shows 59 per cent efficiency in a wind-tunnel test, where the quantities can be actually measured, this is the real efficiency of the propeller in question under the conditions of the test, and no amount of mathematical or theoretical investigation will convince me to the contrary. The airplane horsepower required curve shows the horsepower required to propel the plane at any angle of attack, and this is relative to the air and regardless of the path of the plane. The horsepower available depends on the characteristics of the powerplant, including the engine and propeller and, as I clearly demonstrated, the propeller efficiency is a function of the speed of advance or the quantity V/ND. The curve of horsepower required, therefore, shows at any particular speed of advance of the airplane the actual horsepower effectively delivered by the propeller, and the difference between the power required to propel the plane and the actual power delivered is available for lifting. The brake horsepower required of course is much greater, but in the computation of the horsepower available the effects of the reduced speed in the climb are taken care of. The propeller chosen for the example was selected for the purpose of illustration and not because it was the most efficient possible. Both Eiffel's and Durand's experiments have shown that efficiencies as high as 80 per cent are entirely possible.

I am glad to note that Mr. Loening considers that his monoplane type of structure can be developed to take care of great loads. I have not personally investigated the possibilities of such a structure for heavy-load carrying, and I may be conservative in assuming that when great loads are to be carried it will be found that the conventional truss arrangement of the biplane structure will be found more economical as to weight of structure and equally efficient aerodynamically where proper care is used in streamlining all the elements involved.

Digitized by Google

OPERATIONS OF NAVAL AIRCRAFT

By Commander J H Towers, U S N

THIS article, written shortly after the signing of the armistice, deals with the Naval aviation situation at the outbreak of war and its development during the war, ending with a brief discussion of the probable future lines of development. Figures are given showing the expansion occurring during the nineteen months of warfare, and the different ways in which the various types of aircraft were used. Future development is treated briefly, but that logical assumptions were made is indicated by the fact that the year which has elapsed since the article was written has shown a very decided trend along the lines indicated.

The purpose of this talk on the operations of Naval aircraft is to give a general idea of what this part of the Navy accomplished during hostilities and what may be expected from it in the near future. To make the subject entirely clear it will be necessary to give a few statistics, but in general such details will be avoided. I should add that the operations of the Marine Section and of certain Coast Guard personnel are included in this account.

At the declaration of war the Navy had only one aircraft station, twenty-two training seaplanes, and a total of thirty-eight aviators. It had no seaplanes fit for service use. Its so-called lighter-than-air equipment was negligible. It was, of course, realized that Naval aircraft would be required, but when, where and in what quantity, nobody could say. The proposed Army aviation program was at this time overshadowing everything else, and very few people realized that the Navy would have to embark on a schedule in any way comparable with that program. Additional orders were placed for training seaplanes and lighter-than-air craft. Additional flying schools were opened, and enrollment in the Naval Reserve Flying Corps was really begun. A special board of officers was sent abroad to study foreign types, and about this time the French Navy requested the sending of a detail of trained and student aviators to France for fur-

[1]Office of Naval Operations, Navy Department, Washington.

Digitized by Google

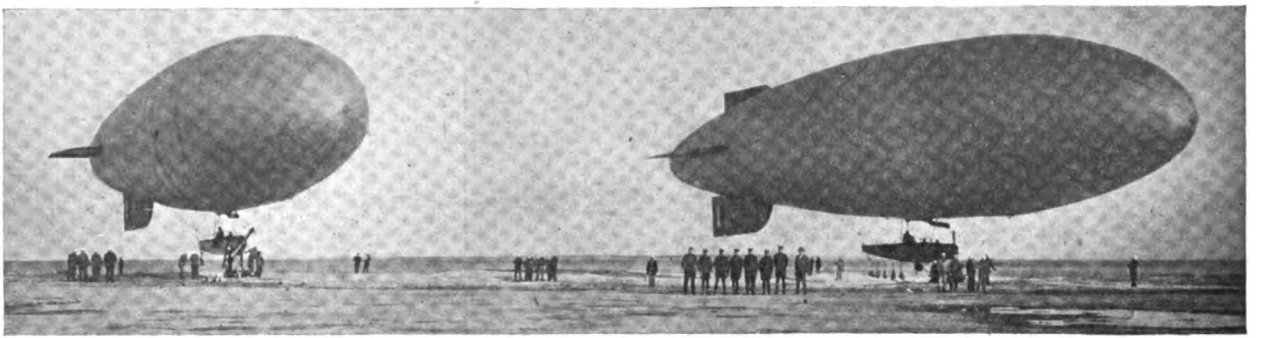
ther instruction, to assist eventually in combating the submarine along the French coast. It is interesting to note that this detail of Naval aviators was the first organized American force to land on French soil.

Adoption of Naval Aircraft Program

When the board returned from abroad, with even more startling facts than we had theretofore had regarding the submarine menace and the efficacy of aircraft in dealing with it, it became obvious that we must not only put over aircraft of a type far superior to any we then had in the Navy but also get them out in what at that time appeared to be astounding quantity. After what might be termed a heartbreaking session, lasting late into the night, a definite program of types was decided upon, and that program was adhered to through many periods of doubt and criticism. This adherence resulted in uninterrupted production, and the performance of the aircraft vindicated those who were responsible for the selection of the types.

From this time on the situation developed rapidly, and by late summer the Navy was embarked on an astonishingly large aviation program on both sides of the Atlantic. When the armistice was signed there were in operation twenty-eight U. S. Naval Air Stations abroad, thirteen in the United States and insular possessions and two in Canada and twelve land squadrons for special offensive operations against submarines at their bases, to say nothing of the numerous schools, storehouses, assembly plants, repair depots and the aircraft factory, etc., required to furnish the necessary facilities for the operation of these stations. The total aviation personnel numbered over 42,000, a figure nearly as large as the total personnel of the entire Navy at the outbreak of the war. Our problems of supply were very difficult, as the primary function of the stations, which was the "strafing" of submarines and the protection of shipping, necessitated the location of stations at strategic points, regardless of communications. These locations abroad extended from the northern end of Ireland to the southern part of Italy, and included the Azores. Eight were located on islands offshore, necessitating considerable special water transportation. Very few were in settled communities; hence they were compelled to be completely self-sustaining.

Digitized by Google



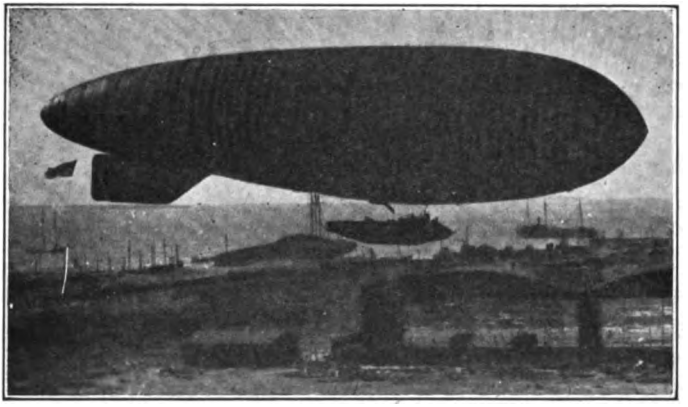
Two of the Naval Airships Ready for Flight

Digitized by Google

Little has been published as to the nature and extent of Naval aircraft operations during hostilities. As I stated before, our primary mission was the destruction of the enemy submarine, wherever it could be found, and second only to this was the protection of supply and troop ships. The primary mission was purely offensive, and its execution, rather varied in form, was as follows:

Routine overseas patrols
Emergency or S.O.S. patrols
Bombing submarines in their bases

Seaplanes of large cruising radius and airships were



THE NAVY DIRIGIBLE C-1 ARRIVING AT KEY WEST UPON THE COMPLETION OF ITS FLIGHT FROM ROCKAWAY BEACH, N. Y.

used for routine patrol. Each station had a zone assigned to it and covered that zone as thoroughly as possible from daylight to dark. The patrol routes were so laid out that the greatest area was covered with the least possible mileage, and each seaplane traversed courses which were carefully laid down in the flight instructions to the pilot. These aircraft were armed with bombs of either 230 or 500 lb. and also with machine guns for use against the submarine crews encountered on the surface or against hostile aircraft. The seaplanes would stay out from 4 to 9 hr., depending on the distance they had to cover, and the airships sometimes stayed out over 40 hr. In some cases these patrols took the seaplanes near islands where rest or refueling stations were provided, as at Bimini in the Bahamas. The

Digitized by Google

erection of these auxiliary stations resulted in practically doubling the extent of operations in these localities.

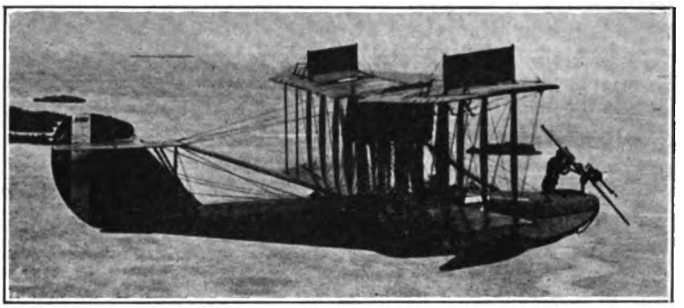
A Typical Day's Work

Following is a sample of a pilot's log for one day, March 15, 1918:

Called at 4 a. m. for inner patrol in H-12 No. 4545
5:30 Left water—dark
6:10 Sighted Kentish Knock Light Vessel
6:40 Sunrise
7:10 Sighted torpedoed British destroyer F-90 being towed toward Harwich by torpedo boat destroyer F-31
7:10-7:30 Searched area
8:15 Shipwah Light Vessel
8:25 Sighted two Hun mines—sank them both—machine-gun fire. Reported their position to base by wireless telegraph
8:40 Six trawlers sweeping
9:00 Sunk Light Vessel
9:20 Landed
2:00 p. m. Three machines left water—No. 4280, Capt. Gordon—4285, Capt. Webster—4290, Ensign Hawkins
3:10 Sighted Dutch coast (Hook of Holland)
4:15 Sighted two two-seater Hun seaplanes
4:15-4:35 Dropped bombs and chased hostile aircraft
4:35 Shot down rear Hun in flames—the other got away into the clouds
4:45 Turned west
4:50 No. 4280 (Capt. Gordon) came down, engine trouble—landed O.K. in 6-ft. swells
4:50-5:05 Circled around No. 4280
5:05 No. 4280 took off O.K.—carried on west
5:35 Sighted large Hun mine-laying submarine 4 miles off port bow fully blown on surface. Opened out for him. Fired recognition signals—no answer. He got under just before we reached him. We had only Lewis guns, as had dropped bombs
6:10 Sighted North Hinder Light Vessel
7:00 Sighted coast—Orfordness
7:20 Landed Felixstowe—dark
Total flying time for day, 9 hr. 10 min. in air

The emergency or S. O. S. patrol was made only when a submarine was reported as being in the zone covered by the station, a limited number of seaplanes being held

Digitized by Google



THE H TYPE NAVY FLYING BOAT EQUIPPED WITH A DAVIS GUN IN THE AIR

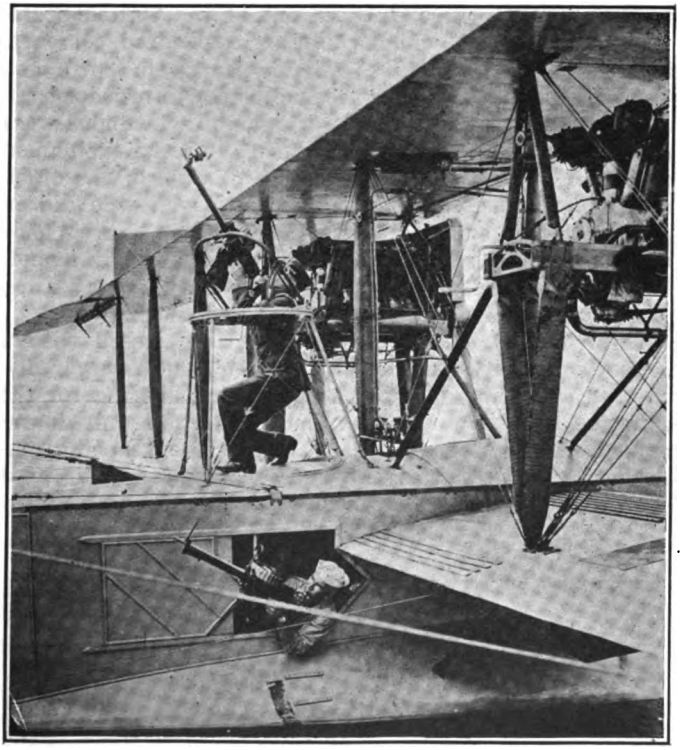
in reserve for such an emergency. Successful accomplishment of a mission depended almost entirely on the rapidity with which fully-equipped planes could be got off with complete written instructions as to the supposed location of the submarine, total area to be searched, etc. On surprise inspection of the northern stations in the United States, shortly before the armistice, emergency patrols were ordered out immediately upon the arrival of the inspection board, and although orders were entirely unexpected, it was found that the longest time required by any of the stations to get out orders, get two HS-1 type planes launched. completely equipped and manned and in the air, with full instructions, was 7 min. This shows the facility with which seaplanes can be operated compared with surface craft.

During the late winter of 1917-18 and early spring of 1918 it was noticed that the aircraft operations were becoming so effective that submarines were more or less consistently avoiding the areas which could be covered by aircraft from the various stations of the Allies and the United States and were extending their operations much farther out to sea. They were able to do this because of the increased radius of action of the larger submarines. Of course, their chances of getting ships were reduced, as they were not within the cone-shaped area through which all ships making for or departing from a port would have to pass, but, on the other hand, if they sighted an unarmed ship without escort, they were so far from the bases that they could sink it before destroyers or other vessels from shore bases could render assistance. It was therefore decided that the proper

Digitized by Google

plan was to attack the submarines in their bases wherever such bases could be reached.

The so-called Northern Naval Bombing Group, consisting of six squadrons of land day-bombing airplanes and six squadrons of land night-bombing airplanes, with complete equipment, was organized to take on this job. The personnel of this organization was partly naval and partly marine. To put this organization in the field required a very speedy modification of training plans, and great assistance from the Army in the supply of material. A land training school of considerable size was got under way by the marines, night flying training was instituted at Pensacola, Fla. and a large number of pilots were sent to British schools and service squadrons. Although the cessation of hostilities came before this North-



GUN MOUNTS ON A NAVY AIRCRAFT

Digitized by Google

ern Bombing Group got into full swing, it accomplished a considerable amount of good work and would undoubtedly have been a decidedly sharp thorn in the sides of German submarine warfare. Various other offensive plans were under way, and a large number of experiments for the purpose of developing new uses for aircraft were being carried on. Since these did not appear in the field they must necessarily be kept secret, at least for the time being.

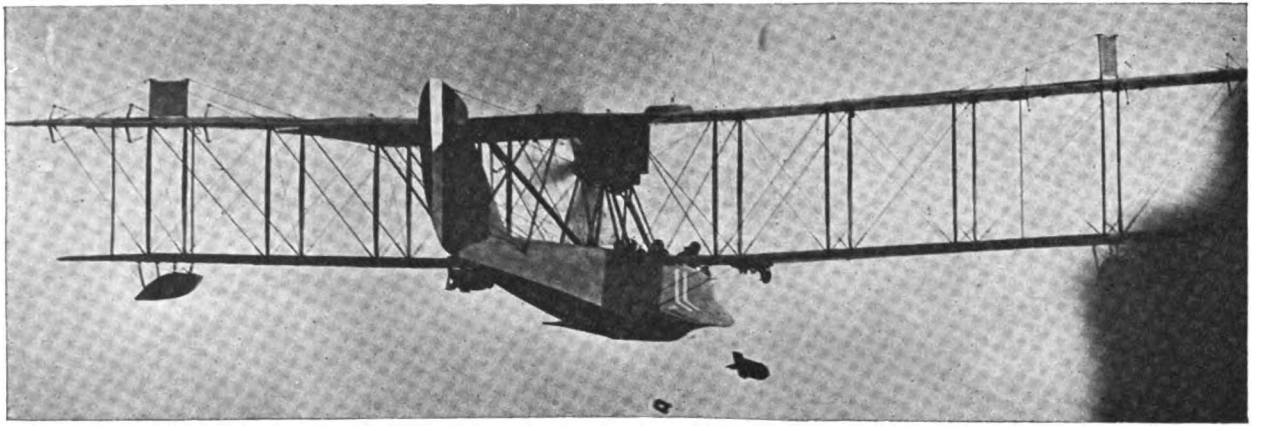
Escorting Convoys

The secondary function of seaplane patrol related to the escort of convoys. The very large overseas transportation of troops and supplies required that all possible protection be afforded, and aircraft, especially airships and kite balloons, were used most extensively in this work. Convoys were escorted out of the United States ports to distances which could be considered comparatively safe and were met outside European ports and escorted in. That so few troopships were torpedoed can be credited, to a considerable extent, to the arduous work of the aircraft. This work did not offer the excitement and interest of flying at the Front, or even of the offensive sea patrols, and the officers and men who did it. day after day, summer and winter, deserve a great deal of praise. And yet convoy escort was not wholly monotonous or devoid of interest; witness the case of an American seaplane operating off the French coast.

On April 23, 1918, while on morning patrol with a convoy of twenty-six American vessels, the observer discovered an enemy submarine awash and steering for the convoy. Two minutes later she submerged, only to reappear close to one of the vessels. The seaplane maneuvered directly over the undersea boat and dropped one bomb, scoring a direct hit close to the conning tower.

The NC-1 Seaplane

Digitized by Google



BOMB BEING DROPPED BY A NAVY FLYING BOAT

Digitized by Google

At this time the top of the conning tower was showing about 2 ft. above the surface. Wreckage strewed the water, and sufficient was gathered up by trawlers later to determine the type of the destroyed submarine. While destruction of enemy submarines by U. S. seaplanes was far from being the usual thing, it can positively be stated that this was by no means the only instance of its kind.

During the latter part of the hostilities certain of our dreadnaughts in the war were equipped with fast planes for spotting, fighting and reconnaisance. The inactivity of the German fleet did not give any opportunity for a demonstration under battle conditions of the usefulness of these aircraft. There is no doubt, however, as to the increased necessity of having the fleet, especially the scouting forces, amply equipped with airplanes.

As has been stated, the primary mission of Naval aviation during hostilities was waging war against the submarines, and this naturally resulted in a rather one-sided development. We now have an opportunity, however, to look into the future and consider what lines of development will be most needed to make aviation an efficient and well-balanced arm of the Navy, and particularly of the great fighting force, the fleet.

Future Development

I believe that Naval aviation development for the next few years will be along the following lines:

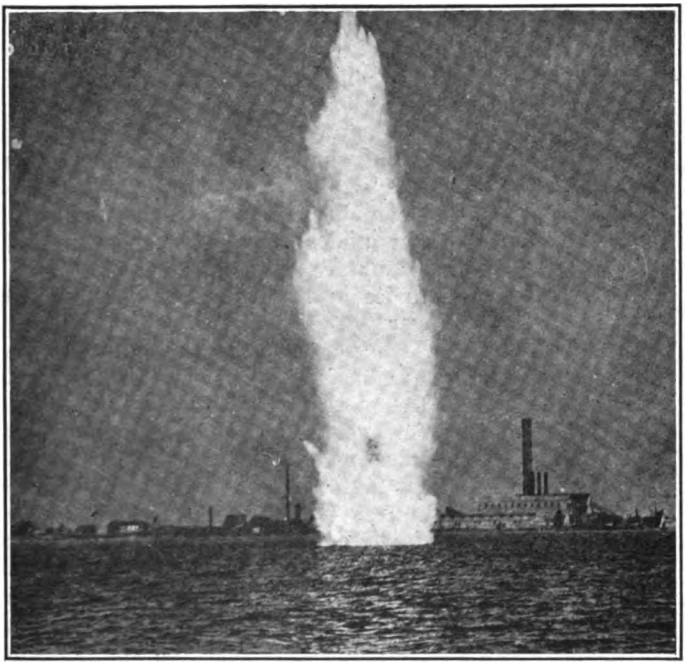
(1) Small airplanes or seaplanes for use from fighting ships for spotting, short distance reconnaisance and fighting
(2) Medium-sized airplanes or seaplanes for use from large high-speed ships with "flying-off" decks or special launching and recovering arrangements, for medium-distance reconnaisance, torpedo carrying and bomb dropping
(3) Kite balloons, and possibly airships, capable of being towed, to be carried by scouts and capital ships for spotting and reconnaisance purposes
(4) Large seaplanes and airships to be based on shore for operations with the fleet and for operations as an independent Naval force when needed

Under the first class the sizes are necessarily limited by the fact that they must operate from a fighting ship and not interfere with the primary function of that ship. Land-type airplanes are easier to launch, and have better fighting qualities, but on the other hand they must either

Digitized by Google

return to shore or to a ship with flying-off deck, or land in the sea, with almost certain damage. Will their usefulness offset these disadvantages? That remains to be seen.

Under the second class, that of medium-sized aircraft for use from special ships, the question again arises, shall they be airplanes or seaplanes? There is no doubt about their being able to fly from and land on the decks



COLUMN OF WATER THROWN UP BY AN EXPLODING DEPTH BOMB

of special ships under reasonably good conditions, but in cases of engine failure we again have the airplane in the water. The launching of seaplanes by catapult has been developed to a satisfactory point, and several methods of recovering the seaplanes without stopping the ship have been suggested. Some of these methods have considerable merit, but require a vast amount of experimentation. Airplanes of the types desired are already in existence. The seaplane characteristics will be af-

Digitized by Google

fected largely by the method of recovery to be used. I think it probable that a 300-hp. type will be selected.

Under the third class, those operating from shore bases, come the big seaplanes and the medium and big airships. The limit to the size of the seaplane is an engineering matter; what is wanted for operation is seaworthiness and long radius of action. I have no doubt that in a few years this type will be of several thousand horsepower, and it may have a steam power-plant. These seaplanes will compete with destroyers. They naturally have the advantage of speed and vision, but must also be able to navigate accurately for long distances out of sight of all fixed marks, to land in and rise from fairly rough water to exercise right of search and must be so reliable and self-sustaining that they return to shore bases only as a destroyer returns—for rest, refueling and overhauling machinery. Until this stage is reached they will be looked upon as nuisances, necessary, perhaps, but undesirable, especially if they make continued calls on surface craft for help.

The rigid airship in its present stage of development has an advantage over the seaplane for long-distance work over the seas. The performance of rigid airships during the last 2 years has been marvelous. They are bound to be one of the most important aids of a fleet. I believe that in a few years it will be considered as foolish for a commander-in-chief to proceed far to sea in time of war without rigid airships well out ahead of his first line of scouts, as it would now be considered for him to go out without scouts. Again, however, these airships must be capable of taking care of themselves. The successful production of argon has removed their greatest handicap, which has been vulnerability, but they still require nursing when they are on shore. At the present time, the shed on shore to house the airship costs almost as much as the ship itself, and the ship can be taken in and out only in good weather and with the aid of hundreds of men. They must be so built that they can moor, as a ship anchors, and ride to that mooring, good weather and bad. Then we can have mooring masts all along the coast and in the insular possessions and sheds only at repair stations to be used for overhauling as the drydock is used for a ship.

It is obvious that America has gone far in the past 18 months in the development of aircraft, but

Digitized by Google

when the specifications outlined for proper military performance are considered it is equally obvious that there is still a long distance to go. Reliability of powerplants is, after all, the prime requisite, and it is principally to the automotive engineers that we look for assistance in obtaining such reliability that the pilot can forget about his engine once he takes the air.

THE LIBERTY AIRCRAFT ENGINE

By J G Vincent[1]

THE history of the development of the Liberty engine is first presented, followed by a discussion explaining how its features worked out in actual practice and what changes in its construction appeared desirable after experience with thousands of the engines on the test stand, at the test flying fields, in the schools and on the battle front. This history is a strong argument for reasonable preparedness; the Government was totally unprepared and had only a small basis for a beginning. The early work of the Aircraft Production Board, the sending of a commission abroad to study design, make recommendations and collect information, and the coming of a technical commission to this country to act in an advisory capacity, gave the much needed impulse and work was begun. At that time no firm in this country was building aircraft engines that would have been of any real value on the fighting line. England and France were working on thirty-seven and forty-six different types respectively. This was a chaotic condition.

The story of preliminary conferences, the actual laying out of the work, the assembling of an engineering organization and the building and testing of the first engine complete the first part of the paper. Many illustrations and much detailed information are included in the description of the most important engine parts. The crankshaft, connecting-rods, pistons, propeller-hub, crankcase, cylinders and crankshaft housing are in turn discussed and the lubrication, cooling, ignition and carburetion systems are next described. A section is devoted to air performance, giving comparative figures relating to foreign planes.

[1]Vice-president of engineering, Packard Motor Car Co.

Digitized by Google

Up to the time the armistice was signed, the Government maintained a strict censorship over details of its war equipment, and for this reason very little was known about the details of the Liberty aircraft engine outside of military circles. Since the signing of the armistice this censorship has been lifted, and very complete detail information covering this engine has been published. The cuts and data already published are quite accurate, and hence it seems unnecessary to give a detailed description in this paper.

It was decided to divide this paper into two parts, covering, first, the historical side of the Liberty aircraft engine; and second, a discussion of its features, explaining how these features worked out in actual practice, and what changes in the construction would appear to be desirable after extensive experience with thousands of these engines on the test stand, at the test flying fields, the schools and on the battle front.

The historical side of this development is, in my opinion, one of the very best arguments for reasonable preparedness, and I think that, as an engineer, I would not be doing my full duty to this Society or to our country unless I gave my brother engineers as complete a picture as may be possible of the difficulties encountered due to lack of preparedness in our Air Service when war was declared on April 6, 1917.

I urge all members of the Society to give this matter careful thought and to do everything in their power to further the development of military aeronautics in this country, as we may not be so fortunate the next time in having allies to stand between us and the enemy while we spend a year laying the fundamental basis for an Air Service, as was the case in the recent emergency.

I will endeavor to set forth clearly just what happened in extensive use of the engine. It may well be that all engineers will not agree with me in some of my conclusions, but I shall endeavor to be entirely unprejudiced, and my statements will be based on what I believe to be the consensus of opinion of the many experts with whom I was associated in the Engineering Division of the Bureau of Aircraft Production at the time the armistice was signed.

To understand why certain moves were made it is necessary to have a clear picture of the aircraft situation as it existed in this country when we entered the war. We were totally unprepared. The Government had no

Digitized by Google

adequate engineering organization, no production organization, and no samples or drawings of engines, airplanes, instruments or armament of any value for military operations on the battle front; neither did it have any definite information regarding designs being used by our allies. We had to start from absolutely nothing. Realizing the seriousness of the situation, General Squier immediately arranged a number of very important moves, and knowing that the obtaining of proper equipment was very largely a commercial matter, he gathered around him a small group of men of undoubted engineering and business ability. Among these were Howard E. Coffin, Edward A. Deeds and S. D. Waldon. These men, together with General Squier and a few others, began immediately to operate as an Aircraft Production Board.

Early Work of Aircraft Production Board

One of the first moves of this Board was to arrange to send a commission abroad to study airplane designs, make recommendations covering machines to be copied and put into production, and send information about such machines to America at the earliest possible moment. Major R. C. Bolling headed this commission, and took with him Captain Clark, an airplane engineering expert, and Howard C. Marmon, an engine expert. Captain Clark had been head of the very small airplane engineering organization which existed as a part of the Signal Corps at the beginning of the war, and he was chosen because he was as well informed on this subject as any other man in America. Howard C. Marmon was selected as he had had a long experience on automobile engines and was a highly trained all-round engineer. He resigned his position with the Nordyke & Marmon Co. to take up this work, at the personal request of General Squier, and he was commissioned as a Captain in the Reserve Corps after he had been in Europe for some time. This commission left for Europe about June 15, 1917. While these preliminary moves were being made in this country, our allies, realizing our state of unpreparedness, had sent a technical commission to this country to act in an advisory capacity so that we might get something started along the right line with the least possible delay.

A combined group of French and English experts visited Detroit on May 26, 1917. I conducted them through the aircraft engine experimental department of the Packard company, and explained the development work

Digitized by Google

that had been carried on there for 2 years. They seemed to be very much pleased with the quality of the work and the general details of design of the Packard aircraft engine, and stated that it would no doubt be a very fine engine for certain kinds of work, but that its power-weight ratio was too great to make it of any real value in an uptodate military airplane. The engine would develop about 235 hp., and without water or radiator weighed a little under 3½ lb. per hp. We had a very thorough discussion of the aircraft situation, and the commission gave us many valuable hints in connection with the latest developments in Europe. I realized that there was not a single firm in the United States working on aircraft engines that would be of any real value on the fighting line.

I read later that there were at that time about thirty-seven different kinds of aircraft engines being manufactured or experimented upon in England and some forty-six different kinds in France. This multiplicity of design not only made for high price and low production, but also caused great complication in the field, as it was next to impossible to keep on hand proper repair parts for all types of engines.

I discussed the situation with the president of the Packard Motor Car Co., who appreciated the need for a standardized line of aircraft engines, and suggested that we communicate with Mr. Coffin. I left Detroit for Washington on May 27, in company with R. D. Chapin of the Hudson company. We had a conference with Messrs. Coffin, Deeds and Waldon. I pointed out the absolute impossibility of obtaining a large production of aircraft engines in this country if the various factories were left alone to go their own way in the designing of aircraft engines. I told them that if it was going to be necessary for the automobile industry to build a large number of aircraft engines they must be furnished with a proper standardized design, so that they would not have to waste any time in experimental work. I pointed out the fact that the Packard engine was too low-powered and too heavy, but that this could easily be remedied by increasing the piston displacement and lowering the factor of safety. I explained that this engine had been designed to weigh under 4 lb. per hp. and run for the longest possible time without overhaul, and that it was the result of specifications put up to me by the Government about two years before, but that since then

Digitized by Google

aircraft development had been rapid, with the result that conditions were entirely changed. I pointed out that the French and English commission had stated to me that a fighting airplane must be equipped with an engine of the lightest possible weight per horsepower, which meant that it must be designed with the lowest possible factor of safety that would serve satisfactorily for a reasonable length of time.

Designing the First Engine

After discussing the matter at some length, Mr. Deeds suggested that he would like to have me meet E. J. Hall. On May 29, Mr. Deeds, Mr. Hall and I met just before noon, at the New Willard Hotel, Washington, and went carefully into the situation, so that we might promptly make a joint report on the aircraft engine situation in this country. By mid-afternoon Mr. Hall and I were ourselves laying down two views of a proposed eight-cylinder aircraft engine.

To get started promptly, we called Mr. Zimmerschied, who was then in charge of the Society's Washington office, and asked him to get us a draftsman and some drafting materials. He could not find a draftsman, but sent over his own drafting instruments. We purchased drafting tables and supplies, and were soon busy. I laid out a transverse section, and Mr. Hall a longitudinal one. We were very well informed on all engines manufactured in the United States and also a great many of the foreign makes, but we, of course, also wanted the latest information on British and French engines. We appealed to Major Souther of the Signal Corps, and he immediately assigned Charles B. King to get this information for us.

That evening Mr. Deeds called a session at the New Willard, at which members of the French commission were present. By this time Mr. Hall and I had prepared specific questions, and they were answered quite fully by the French officials. The next morning Mr. Zimmerschied turned over to us one of the S. A. E. volunteer helpers, J. M. Schoonmaker, Jr., of Pittsburgh. Like Mr. Hall and myself, Mr. Schoonmaker had done no drafting work for a number of years, but nevertheless he did not hesitate to go to work. I turned the drawing that I was making over to Mr. Schoonmaker, and proceeded to dictate a report to the Aircraft Production Board, which Mr. Hall and I had agreed upon the night before. I re-

Digitized by Google

produce this report herewith, as I believe it clearly sets forth our understanding of the situation at that time:

At your request, we have made a careful study of the aircraft engine situation, and hasten to submit our report, as follows:

To get this report into your hands promptly, we have condensed it as much as possible, and have covered the essentials only. In view of the fact that there are a number of good engines for training machines available, we have disregarded this type of engine, and confined our attention strictly to the high efficiency, low weight per horsepower type, such as is needed at the front.

In order that the engines built by this country may be of any value when received at the front, it is, of course, absolutely necessary that their efficiency be brought up to, or a little beyond, the best now available in Europe. The French and English commissions have enabled us to obtain this information by answering our questions very clearly and completely. From information obtained from these gentlemen and from other sources, we believe that the Lorraine-Dietrich is the coming engine in Europe. This engine has not been built in large quantities as yet, but some thirty have been constructed and carefully tested out at sea level, and also at about 6000 ft. elevation.

The important facts about this engine are as follows: Eight cylinders, 120-mm. bore by 170-mm. stroke; cylinders made of steel with water-jackets welded on. Engine is direct-driven and develops 250 hp. at 1500 r.p.m. and 270 hp. at 1700 r.p.m. The weight of the bare engine is 240 kg., or approximately 528 lb., while the weight of the engine complete, with radiator and water, is 305 kg., or 671 lb. There seems to be a reasonable doubt regarding the exact weight of the bare engine, as, while the French commission gave us the figure of 528 lb., information from other sources indicates a weight of 552 lb. Probably some intermediate figure is more nearly correct, but in any event the engine gives a horsepower for approximately 2 lb. of weight when figured at its maximum output of 270 hp.

After obtaining this information and considering the matter very carefully, we next investigated the manner of testing such an engine, as we knew that an engine of this type could not be run at full power for long periods of time without developing serious trouble. Here again the French commission gave us valuable information. They stated that in using an engine of this type it is only run at full power for short periods of time, while climbing or fighting, and that at all other times it is run at speeds 200 to 300 r.p.m. slower.

Digitized by Google

In view of the fact that the engine is built to run under these conditions it is, of course, necessary to test it under a similar condition, and they stated that when trying out a new model of engine it is their practice to mount a propeller which will just hold the engine down to maximum speed under full throttle. The engine is then run for 50 hr. in periods of 6 to 8 hr. each, but the engine is not run up to full speed for more than a total of 10 hr. during this entire period, nor is it run more than 30 min. at any single time under this condition. The other 40 hr. running is under throttled condition, turning the same propeller at 200 to 300 r.p.m. less than maximum speed.

This information is of the utmost importance, as it enables us to reduce all factors of safety and makes possible the light weight per horsepower now being obtained in Europe. After securing this information, we immediately laid down a proposed engine, which we believe can be produced promptly in large quantities in this country. Built carefully out of proper materials, this engine will have approximately the following characteristics and be as good, or a little better, than the Lorraine-Dietrich, which is not as yet really available abroad. In laying down this engine we have, without reserve, selected the best possible practice from both Europe and America. Practically all features of this engine have been absolutely proved out in America by experimental work and manufacturing experience in the Hall-Scott and Packard plants, and we are, therefore, willing to stake our reputations on this design unhesitatingly, provided we are allowed to see that our designs and specifications are followed absolutely.

The engine is to be of the eight-cylinder type, with cylinders set at an included angle of 45 deg. The cylinders are of the individual type, made out of steel forgings, with jackets welded on. The bore is 5 in. and the stroke 7 in., giving a piston displacement of 1100 cu. in. The crankshaft is of the five-bearing type, with all main bearings 2⅜ in. in diameter and all crankpin bearings 2¼ in. in diameter. The connecting-rods are of the I-beam straddle type. This engine is of the direct-driven type with a maximum speed of 1700 r.p.m. It will have a maximum output of 275 hp. at 1700 r.p.m. and will weigh 525 to 550 lb., but we feel very sure of the lower figure. It will have a gasoline economy of 0.50 lb. of fuel per hp.-hr. or better; it will have an oil economy of 0.04 lb. of oil per hp.-hr. or better. Complete with water and radiator, this engine will not weigh more than 675 lb., if a properly constructed radiator is used and placed high above the engine. To obtain the above mentioned

Digitized by Google

weights, it will be necessary to use the fixed type of propeller-hub, which has been thoroughly proved out by Hall-Scott practice. It will also be necessary, as mentioned above, to use the very best material, workmanship and heat-treatment.

Complete detail and assembly drawings, as well as parts lists and material specifications, can be completed at the Packard factory under our direction in less than four weeks. We believe that a sample engine can also be completed in approximately six weeks, if money is used without stint. As soon as the drawings, specifications and a sample engine have been finished, complete information would, of course, be available, so that any high-grade manufacturer could either make parts for this engine or manufacture it complete.

In laying down this design, we have had in mind the extreme importance of interchangeability, as a well laid comprehensive program, which has for its base interchangeability of important parts, such as cylinders, will speed up output and reduce ultimate cost to an astonishing extent. Europe is suffering right now from lack of uniformity of design, but it is too late for them to change their plan. We, however, can take a leaf out of their book and start right.

In the design which we have laid down, the cylinder, for instance, can be used to make four, six, eight and twelve-cylinder engines. As this is the most intricate part to make, immense facilities could be provided to produce them in large quantities for the use of many concerns who could manufacture the rest of the engine. Nearly all small parts, and numerous large and important ones, would also be interchangeable. This would not only speed up production, but would be of the utmost importance in connection with repairs and replacements. A full line of engines made according to this plan would be about as follows:

Type	Rated hp.	Maximum hp.	Weight, lb.	Weight per hp., lb.
4	110	135	375	2.7
6	165	205	490	2.3
8	225	275	535	1.9
12	335	410	710	1.7

Respectfully submitted,
(Signed) J. G. VINCENT.
(Signed) E. J. HALL.

The above report was finished on the afternoon of May 31, and we had at that time got the cross-section and longitudinal section drawings fairly well blocked out. About 3 p. m., Mr. Waldon telephoned Mr. Hall and me to bring our report and drawings over to General

Digitized by Google

Squier's office in the Army and Navy Building. When we arrived we were promptly shown into the conference room, where a joint conference of the Army and Navy and Aircraft Production boards was in session, with Mr. Coffin in the chair. Mr. Coffin called for our report, and we asked Mr. Waldon to read it.

Actual Layout Work Started

After the report was read we were asked to explain the drawings, which we did as quickly and clearly as possible. We, of course, explained that these drawings were only intended to show the general idea, and that we could, however, get layouts made quickly if our suggestions met with favor. We were immediately requested to go ahead with all possible haste and make good layouts. We wired to Detroit for two good layout men, and they arrived about noon, Friday, June 1. Messrs. Hall, Schoonmaker and I kept right ahead with our layouts, on which we were determining construction features. This allowed good layout men to go ahead with the finished layouts of settled construction. We all worked without stopping until Monday afternoon, June 4. By that time the layout men had finished good, accurate layouts of the longitudinal section, transverse section, rear elevation and camshaft assembly views of the eight-cylinder engine.

About the middle of the afternoon of June 4, Mr. Hall and I were again requested to go before the joint committee of the Army and Navy, with the Aircraft Production Board, to make a further report. We exhibited the finished drawings and went somewhat more into detail than had been possible at the previous meeting. After we had explained the drawings we left the conference with Mr. Deeds, who was just starting for Dayton. Mr. Deeds told us that it had been decided that we should build ten sample engines, five of the eight-cylinder size and five of the twelve-cylinder, and asked us to "go to it" and produce the first sample eight-cylinder engine at the earliest possible moment. He told us he had promised that we would finish the first sample eight-cylinder engine in seven weeks from that date. We immediately sent the layout men home to Detroit with instructions to complete the detail drawings of the long-time parts, such as cylinders and crankcase, immediately.

Mr. Hall went to Indianapolis that night and I went to New York, where I met Mr. Macauley the next morning and explained to him just what had taken place.

Digitized by Google

Mr. Macauley and I returned to Washington on the morning of June 6, and immediately went into conference with Messrs. Deeds, Waldon and Hall. Mr. Deeds explained to Mr. Macauley the great advantage of standardizing a line of U. S. A. engines, and after a little thought Mr. Macauley not only agreed to this very radical step, but also to the loan of my services to the Government for a period of three months so that I might follow up the engineering work which had been started.

Mr. Deeds explained to Mr. Macauley that money had been appropriated to cover the cost of this development, but that he realized that to make good on the deliveries which he had promised I must have the right to order things quickly through commercial channels with which I was well acquainted. To this end he requested Mr. Macauley to arrange with the Packard Motor Car Co. to buy and pay for anything that I requested for the work, with the understanding that the Packard company would render an accounting, and be reimbursed by the Government. Mr. Macauley agreed to do as requested, stating that this work would be put ahead of anything in the factory, and that I would have the "right of way," not only as to the services of my well-trained experimental organization, but the factory facilities also. This was the day on which the "U. S. standardized aircraft engine" idea was really settled.

As a matter of interest, I will state that Mr. Hall and I designated this line of engines as the U. S. A. standardized line, but a little later I believe Admiral Taylor dubbed it the "Liberty" engine in one of the Aircraft Board meetings, and this name was so popular that we were forced to adopt it, and change all our titles on the drawings.

Mr. Hall and I left Washington Thursday noon, June 7, for Detroit, where we arrived on Friday morning. We went to the Packard factory and looked over the work on detail drawings which had been started. We found that O. E. Hunt had taken very prompt action, and already secured billets of steel from Cleveland out of which to make cylinders for the first engines. Mr. Hall spent the day going over various matters with me and left on the night boat for Cleveland to make arrangements to get crankshaft forgings for the first engine. These forgings, completely heat-treated, were produced in three days, Mr. Hall having given permission to "dig out" his dies.

Digitized by Google

I, of course, realized that to get the first engine quickly we must have detail drawings almost immediately, and I therefore called for volunteers from the various drafting departments of the Packard organization to work Saturday afternoon and Sunday. Every man volunteered, with the result that we had a very large force working Saturday afternoon and Sunday, and during this day and a half approximately 86 per cent of the detail drawings were finished on vellum, from which blue prints could be made. In other words, on the morning of June 11 I was enabled to get blue prints of 86 per cent of the parts, and I immediately began calling on various automobile and accessory manufacturers to rush through enough parts for a first sample eight-cylinder engine.

The crankcase upper and lower halves were, of course, long-time parts, and these drawings could not be finished in a day and a half. We did, however, succeed in getting them nearly enough completed by Wednesday, June 13 to enable us to take off preliminary prints. These preliminary prints enabled us to start pattern work and also a wood model of the engine. Vellum drawings of the upper and lower halves were finished on Friday, June 15, and good blueprints were put in the hands of the experimental pattern shop.

In the meantime, the pattern shop had been working night and day on the wood model, which they succeeded in finishing and shipping to Dr. Stratton at the Bureau of Standards on Saturday. By this time the vellum drawings on all the major parts, except those contained in the oil-pump assembly, had been completed, and enough parts for a sample engine ordered from various factories.

Assembling An Engineering Organization

While all this work was going on during the week ended June 16, the Aircraft Production Board was furnishing engineering offices at the Bureau of Standards, Washington, where space had been arranged for by Dr. Stratton. I left Detroit on Sunday, June 17, with a complete engineering organization, which had been drawn from various automobile factories, including the Cadillac, Dodge and Packard. Engineers were also sent from the Pierce-Arrow plant, and they met us at Washington. I arrived in Washington on Monday morning and imme-

Digitized by Google

diately set to work getting settled in our new quarters at the Bureau of Standards.

In order to "put over" a job of this magnitude in a short time, a tremendous amount of work must be accomplished quickly through the cooperation of a great many people who are peculiarly fitted by their training to do their particular parts without detailed supervision. At this stage the design was practically settled and the work of building samples was well under way. Everybody connected with the job continued to put forth his very best efforts, with the result that our first sample Liberty engine was delivered to the Bureau of Standards, Washington, on July 3, 1917. Additional samples of the eight-cylinder, also samples of the twelve-cylinder, followed quickly, and the first sample twelve-cylinder Liberty finished its first official 50-hr. run at 1.30 a. m., Aug. 25, 1917, having gone through this 50-hr. run in an elapsed time of only about 55 hr., thus breaking all records for tests of this kind. It is usual to run such tests in periods of 5 hr. each, two runs being made each day. In other words, it usually takes five or more days to complete such a test. This 50-hr. test was made under the supervision of Government Inspector Lynn Reynolds, and after finishing his very complete report of the test, he wrote the following foreword:

> The appended report is a survey of the main phases of the 50-hr. endurance test, maximum power curve calibration on electric dynamometer, and inspection of dismantled parts of U. S. A. twelve-cylinder aircraft engine No. 1, which were made under the supervision of the Equipment Division, Signal Corps, at the Packard factory, Detroit, Mich., Aug. 22 to 25, 1917.
>
> A consideration of the data collected, will, we believe, show that the fundamental construction is such that very satisfactory service with a long life and a high order of efficiency will be given by this powerplant, and that the design has passed from the experimental stage, into the field of proved engines.

All the Government officials who had been following this job carefully realized that while no doubt a great deal of detail work remained to be done, this test conclusively proved that we had an engine design capable of being produced in large quantities in this country, and that it would compare favorably with the best designs that had been developed in Europe. Acting on

Digitized by Google

this belief, all possible haste was made in cleaning up the drawings, and complete sets of drawings of both the eight and twelve-cylinder designs were turned over to Lieutenant Emmons, who was in charge of engine production, about Oct. 1, 1917. It was, of course, understood that many detail changes would have to be made in these drawings during the early stages of manufacture.

The First Engine Completed

After careful consideration of reports from abroad it was decided to put the twelve-cylinder engine into production, and hold the eight-cylinder back, as all demands from abroad called for around 400 hp. The first "production" twelve-cylinder engine was delivered at McCook Field, Dayton, Ohio, on Thanksgiving Day, 1917, but it should be borne in mind that this engine was only partially made from production tools. In fact, the first several hundred engines were made more or less by hand to get out a reasonable quantity at the earliest possible date, and thus permit extensive tryouts under actual flying conditions.

During the time this work was going on, Captains Clark and Marmon returned from Europe, and after going over the Liberty engine carefully in the light of what they had learned, agreed that we had been very wise in developing the Liberty engine, because, in their opinion, an engine of 400 hp. was essential for types of machines that it had been decided we should manufacture, and they stated that no proved 400-hp. engine existed in Europe.

Spurred on by this encouraging information, every one concerned put forth his best efforts to get into quantity quality production at the earliest possible date. From this point on the facts are pretty generally known. As soon as the necessary samples could be shipped to Europe they were carefully tried out under actual flying conditions by our allies. First England, and then France and Italy, accepted the engine, and began to negotiate for the purchase of these twelve-cylinder Liberty engines for installation in their planes. Unfortunately, our own plane production was considerably delayed, not so much on account of the plane itself, but by the fact that we did not have in this country the necessary instruments and armament to equip the planes. In other words,

Digitized by Google

the design of the DeHaviland-Four could have been finally settled in November or December, 1917, had information been available as regards all the instruments and arma-

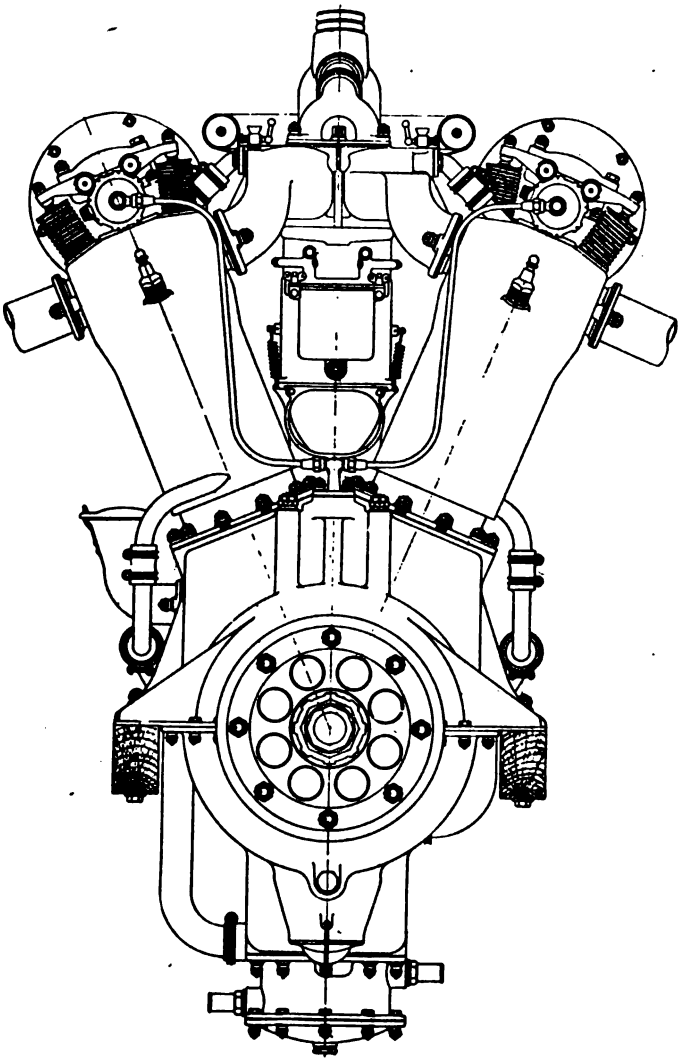


FIG. 1—FRONT ELEVATION OF THE LIBERTY-TWELVE ENGINE

Digitized by Google

ment, but this information did not become available until late in March, 1918. As soon as this information was available the DeHaviland-Four design was quickly

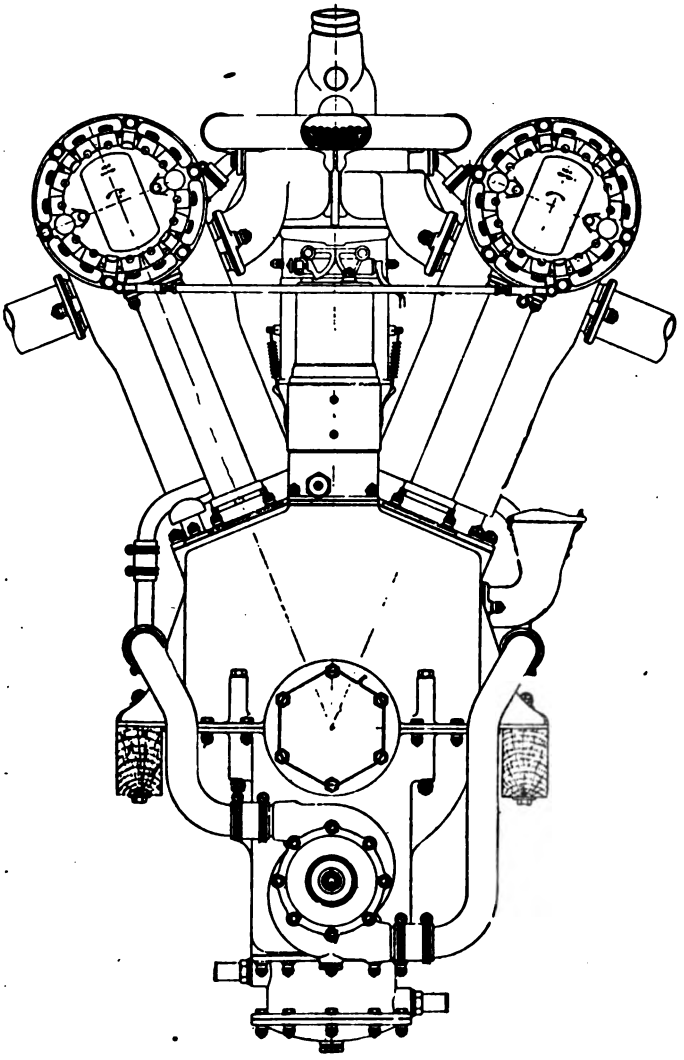


FIG. 2—REAR ELEVATION OF THE LIBERTY-TWELVE ENGINE

Digitized by Google

cleaned up, and I believe that a real record was made in getting it into production after that time.

What the Tests Revealed

As soon as these planes became available they were extensively tested both in this country and abroad, with the result that numerous minor faults were developed, which had to be corrected. The extensive test work of the Liberty-DeHaviland combination also developed several shortcomings in the Liberty engine, which had to be corrected after production was fairly well under way in one plant. In this connection, however, it is interesting to note that the correction of none of these difficulties involved any radical change in the basic design.

It is now a well-known fact that the DeHaviland plane equipped with the Liberty Twelve did wonderful work at the front, and that it was considered the best all-round plane available at the time the armistice was signed. It is also a significant fact that England, France and Italy were taking deliveries of these engines just as fast as they could get them, and installing them in their various types of observation, two-seater fighting, day bombing and night bombing machines.

The fact that no tried 400-hp. engine existed in Europe was one good reason for developing the Liberty engine, but other equally good reasons existed. The engines developed by our allies had been built under extreme pressure. There were so many different kinds that none of them was made in any great quantities. Probably the two best foreign engines at that time were the Rolls-Royce and the Hispano-Suiza. According to information received at that time, the Rolls-Royce developed about 350 to 375 hp., and was recognized as probably the best large engine available for our allies. It was, however, developed for European manufacture in small quantities, and was composed of a great many intricate parts, which would be very hard to manufacture in quantity under American production conditions. For example, many of the important forgings would have had to be made much better than had been our practice in this country. The Liberty engine was designed to be as reliable as the Rolls-Royce, develop a little more power, be a little lighter per horsepower and cost about one-half as much. These aims have all been accomplished.

The Hispano-Suiza was a smaller engine, and as it

Digitized by Google

was already in production in this country, and continued to be produced in increasing quantities, it need not be considered in this discussion.

The Lorraine-Dietrich eight-cylinder engine, which it will be remembered was held up to Mr. Hall and me as the coming aircraft engine in Europe, did not come through the experimental stage as fast as had been anticipated. While Captains Clark and Marmon were in Europe they examined both eight and twelve cylinder models of this engine, but upon their return stated that it had not yet gone into quantity production, and as nearly as they could determine these engines were still in the experimental stage. Our Government had for months a standing order to ship one of the twelve-cylinder Lorraine-Dietrich engines to us, but it was never received. It is obvious, therefore, that it would have been a great mistake to depend on putting either of these Lorraine-Dietrich engines into production in the United States.

The only other allied engine that looked at all interesting was the Bugatti, and arrangements were made to bring a sample of this engine to America, so that it might be put into production. As was to be expected, it had to be entirely redesigned for American methods of manufacture, with the result that it was just getting into production when the armistice was signed. This engine was designed for a special type of service and can never be as light per horsepower as the Liberty. It may, however, have distinct military value for certain kinds of work.

A Standardized Line of Engines

To sum up what has been accomplished by the designing of the standardized Liberty aircraft engine, I will state that this development made it possible for the United States to produce large quantities of 400 to 420-hp. reliable light-weight aircraft engines. Handling of the maintenance problem was greatly facilitated, with but one set of repair parts for the vast number of engines manufactured.

I am not in possession of exact information regarding production, but I know that the first production engine was delivered to the Government in less than six months from the date that Mr. Hall and I turned in our original recommendation, and within a year from the date our

Digitized by Google

recommendation was made some five or six large companies were in quantity production, and the output was increasing steadily day by day.

Had the war gone on for a few more months, we would also have been producing the 280 to 300-hp. Liberty Eight in large quantities for single-seater fighting or chasse machines. To take care of the maintenance work on these eight-cylinder engines, it would have been necessary to put into stock only some twelve additional parts, as the eight-cylinder parts are interchangeable with the twelve-cylinder, except as to a few special parts such as the crankcase, crankshaft and the like.

An important advantage of the standardized line of engines, which is ordinarily overlooked, is the matter of installation in planes. To be a good job, all airplanes must be designed around the engine and equipment. Every different type of engine presents many new installation difficulties. We have worked out a standard form of installation for the standardized line of Liberty engines, so that we can give a plane designer definite information as to the engine tachometer, the gasoline system, the oil system, cooling system, the spark throttle and altitude control system, and many other details too numerous to mention.

I have talked with many experts who have been sent over by our allies, and all who have had practical experience at the front state emphatically that the most important thing about a military airplane is to have it reliable, and they, therefore, agree with me that it is very important to have all the systems standardized as outlined above so that the troubles can be eliminated from them. They have stated to me that it has never been possible to work out good standardized systems abroad, because they have had so many different kinds of engines to install. On this account, most of their installations have been more or less makeshifts, and a very large percentage of their failures has been due to failures of some part of these systems, rather than to the engine or plane proper.

I hope that I have made the matter of standardization clear, as I consider it of the utmost importance, but I do not want to be understood as advocating that the Government use only one or two kinds of engines during peace time. The standardized Liberty aircraft engine was designed to meet an actual emergency, and I believe

Digitized by Google

that everybody who is familiar with the facts, will agree that it was a very wise move. On the other hand, it would greatly retard development if the Government did not give careful and unprejudiced consideration to all designs submitted during peace times. If there is to be any real progress in the development of aircraft engines, airplanes or airplane equipment, however, it must be brought about by the cooperation of engineers and proper officials of our Government.

At the present time, the Engineering Division of the Bureau of Aircraft Production and the Technical Section of the Department of Military Aeronautics are being merged into one peace-time organization, which will probably be known as the Technical Section of the Department of Military Aeronautics. This reorganization is being carried out under the direction of Col. T. H. Bane of the Air Service.

The Technical Section of the Department of Military Aeronautics is a mammoth bureau of information, having on file at the present time a complete record of the present state of the art, not only in this country but in all important foreign countries as well. In addition to serving as a bureau of information, this section, through its officers, acts in an advisory capacity to engineers, as critic of designs or sample machines, and as an experimental organization to test out all designs which are submitted. By co-operating with this department, all engineers may secure exactly the same data and advice, and be sure that their equipment will be tested in an unbiased, as well as in a standardized, way. In other words, all engineers will have exactly the same chance, and may be informed beforehand as to just what tests their equipment will have to pass through.

If the Department of Military Aeronautics is given proper support, as it must be if we are to remain prepared in our air service, the Government will be in a position to go into production quickly in any emergency, because the Technical Section will have a complete record of all tests, and will, therefore, be able to select the best equipment of each kind; and, furthermore, it will be in possession of the necessary drawings, specifications, etc., so that in such emergency there will be no necessity for an experimental stage.

In closing this chapter of my paper, I want to urge all engineers who are interested in aeronautics to coop-

Digitized by Google

erate with the Technical Section of the Department of Military Aeronautics, and work for the maintenance of a permanent technical department, in connection with our Air Service, so that we may never again be caught in the pitiful condition that existed in the early part of 1917.

Figs. 1 to 8 inclusive are representative of the Liberty twelve-cylinder aircraft engine as it was being produced at the time the armistice was signed. Figs. 9 to 13 inclusive show certain alterations in the carbureter and intake-header construction, which I will refer to and describe later. I will now take up the important elements of the engine and endeavor to point out the reasons for the design selected, as well as the results obtained.

Crankshaft

Figs. 4 and 5 clearly indicate the general construction of the conventional type of seven-bearing crankshaft. This type was selected because the comparatively large bore and stroke of the engine made it practically impossible to consider any less number of bearings. No counterweights were considered, because the engine is of the direct-drive type, and not intended to run over 1800 r.p.m. At this speed the main bearing pressures, due to centrifugal force, are not excessive. All main bearings, except the front one, are of the same length, which, of course, results in the bearing pressures being highest on the center bearing. Conservative design would have dictated a longer center bearing, but as this would have lengthened the engine and added some weight, we decided against it, as calculations and experience indicated that it was not absolutely necessary. Although this center bearing actually showed more wear in service than any of the others, it was never a source of trouble, as the wear was not excessive. From my experience with these engines, I would make the same decision again under the same circumstances, but would lengthen the bearing about 50 per cent, if I were designing an engine for commercial aviation. In this connection I will also state that for a commercial aviation engine, I would make all main bearing shells ¼ in. thick, instead of 3/16 in., as in the case of the Liberty.

The crankshaft main bearing journals are all 2⅝ in. in diameter and the crankpins 2⅜ in. The crankshaft

Digitized by Google

cheeks, as originally designed, were the weakest point, and when we began to get into quantity production, small variations in material and heat-treatment occasionally resulted in a broken shaft, sometimes within a few hours and sometimes after from 50 to 100 hr. use. It was, of course, impossible to make the cheeks any thicker, and it was, therefore, decided to widen them to take the shape shown in Fig. 4.

So far as I am aware, no crankshafts of the revised design were ever broken, with the exception of the occasional shaft that contained a flaw, and these usually let go before the engine had passed its manufacturer's test. It is my belief that the crankshaft as strengthened is an entirely practical and satisfactory design for this type and power of engine.

Connecting-Rods

The designs of connecting-rods and connecting-rod big-end bearings, as originally specified, were on the light side, and while the connecting-rods themselves would stand up indefinitely, if made out of the best material with the best heat-treatment, the least variation would result in trouble. It was, therefore, decided to thicken all sections about 1/32 in., and while this added weight to the engine, it made a thoroughly practical manufacturing proposition.

One of the sources of trouble with the original design was sharp corners under the connecting-rod bolt heads, and these were generously filleted in the redesign. The trouble with the connecting-rod bearings was that they were too thin, with the result that they went out of shape under heavy load, and the continual distortion would crack the babbitt. These bearings would not burn out or break, but the babbitt would simply disintegrate, with the result that when the engine was taken down after 50-hr. use, the bearings would be in bad shape, and would all have to be replaced. This trouble was entirely overcome by increasing the thickness so that the thinnest portion under the straddle-rod forks was 9/32 in. thick.

The connecting-rods and connecting-rod big-end bearings as finally proved out and standardized, gave a uniformly satisfactory result, and I would not know how to improve them if called upon to do so at this time. We carried out a great many experiments at McCook

Digitized by Google

Field with various kinds of V-type connecting-rods, including the so-called "marine-type," such as is used on the 300-hp. Hispano-Suiza, and the so-called "articulated type," such as is used on the Rolls-Royce. Both of these types can be made perfectly satisfactory, but we could not determine that they were any better than the so-called "straddle-rod type," as standardized for use on the Liberty. The connecting-rod piston-pin bushing, with its splash lubrication, proved entirely satisfactory, which seems to indicate that there is no necessity for carrying pressure oil to the piston-pin.

The connecting-rod length to stroke ratio is 1.71 to 1. This proved satisfactory but I would not recommend designing an aircraft engine with any lower ratio.

Pistons

The die-cast aluminum-alloy piston design, as originally laid down, proved very satisfactory, and was never changed. This piston design was originally dictated by Mr. Hall's experience, as he had proved by extensive experimental work, the value of a very thick head and tapered piston wall increasing in thickness toward the top, in order to be as thick back of the piston-rings as through the head. The purpose of this thick piston head and tapered wall is, of course, to provide for the proper transfer of heat from the piston head to the cylinder wall.

The piston-pin is of the floating type, held in position by aluminum washers pressed into the piston at each side. This construction proved to be very satisfactory and prevented the usual trouble of cotter-pins and set screws dropping into the crankcase.

We had a little trouble at first with the pistons scoring, because they were too soft to work satisfactorily against the steel cylinder. This trouble was quickly cured by making the pistons harder and watching the heat-treatment of the cylinders to get them of a uniform hardness, though still machinable.

Fig. 4 shows the high-compression piston had a compression ratio of 5.4 to 1. The low-compression piston is flat on top but has the same bearing length as the high-compression type. The low-compression piston was used for all Navy engines, as they work at comparatively low altitude, and the high-compression for all Army engines,

Digitized by Google

as they were intended for use principally at high altitude.

Propeller-Hub

As originally designed, the propeller-hub was to be put on the crankshaft permanently, as it was feared that a detachable hub would give trouble in an engine of such large power. This design, however, was contrary to foreign practice, and so much pressure was brought to bear in favor of the detachable hub that the design was changed before the engine was ordered into production.

Fig. 5 shows the propeller-hub as finally designed, including the propeller-hub key running clear out to the rear end. The taper is 1 to 12. The propeller-hub key as originally put into production was short and did not extend within 1 in. of the rear end. This construction gave trouble, in that the hub would freeze on the shaft, making it hard to remove and impossible to replace without filing and lapping.

This trouble was largely overcome and a practical result obtained by extending the key clear to the rear end of the hub and grinding the shaft and hub so that all the draw came at the rear end. By this I mean that the tapers were made so that they did not exactly match, and the front end of the shaft would be perhaps 0.001 in. loose with the rear end drawn up tight. This simply insured that the hub would be absolutely tight at its big or driving end.

The offset hub, as shown in Fig. 5, was really an afterthought to allow room for shutters in front of the radiator, but it proved more satisfactory than the conventional type, due, it is believed, to the reinforcing of the rear flange by the hub extension. The diameters of the propeller-hub flanges and bolt-circle, as well as the thickness of the propeller-hub, proved entirely adequate for the horsepower output of the engine.

Crankcase

As shown in Figs. 1, 2, 3, 4 and 5, the crankcase is of the deep box-section type; the upper and lower halves being lapped together and firmly anchored to each other by numerous bolts around the flanges, as well as long through-bolts on each side of all main bearings. The design of the individual steel cylinders made it possible

Digitized by Google

to extend them down into the crankcase, thus greatly increasing the possible depth and strength of the crankcase, and at the same time making it possible to reduce the included angle between the two rows of cylinders to 45 deg. As is clearly indicated, the main bearings are carried between the upper and lower halves. In my opinion, the design of this crankcase had a great deal to do with the satisfactory operation of the Liberty engine, and I know that no other type could be designed anything like as light and still stand up.

After the Liberty engine had been in production for some months, a well-known English engine expert came to America, and in carefully going over the design of the engine with me, he asked where we got our information as to the design of the crankcase. After I explained its advantages, he told me that they were just then beginning to realize the value of the box-section type of crankcase in England, and that experiments carried out recently had proved to them that this type, with the bearings carried between halves, is a very great improvement over any other design which they had used. The engine bed flange design, including the number of bolts, form of ribbing, etc., has proved entirely satisfactory.

Cylinders

The individual cylinder design was, of course, originally selected on account of the necessity for a seven-bearing crankshaft, but while the design was being laid down it was recognized that the individual design was right for several other reasons. This design made it possible to machine pilots to extend into the crankcase, thus increasing the depth of the crankcase and making it possible to narrow up the angle without weakening the crankcase too much at the center or having the cylinder flanges overlap. The steel cylinders as selected for this make for more simple machining and easier application of the steel water-jacket. This design also permits easy assembling and dismantling of the engine, and therefore facilitates manufacture as well as maintenance. It is very convenient to be able to remove a damaged cylinder quickly without disturbing the remainder of the engine and without removing it from the plane. The design of steel cylinder is shown in Figs. 1, 4 and 5. In my opinion the steel cylinder is the lightest that can be

Digitized by Google

Digitized by Google

Digitized by Google

designed, and its construction provides for the best possible valve cooling. In spite of the fact that the Liberty valve is 2½ in. in diameter in the clear, it cools very satisfactorily, and I have seen a great many engines taken down after 100 hr. flying, with the valves still in good, serviceable condition. Owing to the shape of the steel water-jacket around the spark-plug, considerable difficulty was experienced in producing this stamping, but dies were finally devised which produced a very perfect result with the minimum of scrap.

One of the big manufacturing problems in connection with the steel cylinder was to secure hollow forgings of the proper material, which would provide for the minimum removal of material in machining. This job was submitted to two different companies, the Ford Motor Co., Detroit, and the J. G. Brill Co., Philadelphia. Both worked out a thoroughly satisfactory and economical forging. The Ford company developed a process to make this forging from steel tubing, while the J. G. Brill Co. used a process to make the forgings from billets. One of the difficulties in producing this forging was the fact that its flange is located several inches from the lower end. It is my belief that both companies finally used the same process to produce this flange, consisting of an upsetting operation, with the bore properly reinforced by a pilot.

The valve-port cages are machined from separate forgings and welded on, the camshaft housing support bosses being machined as an integral part of these ports. The design is such as to provide water-cooling for almost the entire length of the exhaust-valve-stem guide. Proper welding on of the steel jackets proved to be simply a matter of practice, to get a good job, and girls were used largely for performing this operation. The only trouble that I have ever heard of in connection with these cylinders was an occasional leak in the water-jackets, which usually occurred at the top of the jacket. This trouble would not occur frequently enough to be of any great importance, but we carried on extensive experimental work in an endeavor to find out what caused it, and came to the conclusion that it was caused by the flexing of the jacket, due to slight distortion of the cylinder head under the force of the explosion. If this is a correct deduction, the trouble could be cured in two ways, one being to put a positive tie between the valve

Digitized by Google

ports and the other to thicken the cylinder-head, say 1/16 in.

Camshaft Housing

The camshaft and housing assembly, as well as the valve rocker-arms, are clearly shown in Fig. 6. This construction proved to be very satisfactory, as it is positive in operation, practically never gives trouble, is quite easy to assemble and disassemble, and throws very little oil. This is the only type of valve-operating mechanism that has given real satisfaction in connection with V-type engines having steel cylinders and exposed valve-springs. It is, of course, a much simpler problem to work out a valve-operating mechanism for cast-in-block engines like the Hispano-Suiza, where the entire valve mechanism is covered and therefore oil-tight.

The arrangement of the driving gears proved very satisfactory after we had overcome the initial troubles, due to bad design, such as lack of proper fillets, metal being cut down too thin under the teeth, etc. During the early manufacture there was a tendency to make these gears too hard.

Some trouble was experienced with the meshing of the bevel gears in the early stages of manufacture, due to the expansion of the crankcase and crankshaft under heat. This trouble was finally overcome by working out the proper clearances and then shimming to that clearance.

The latest Mercedes engines contain a very great improvement, however, at this point. The bevel gear is splined on the crankshaft with a sliding fit, and a separate thrust is provided to locate the gear and determine its mesh. This does away with all variations due to expansion and contraction, and is therefore a great improvement.

Before we had extensive experience with these engines it was predicted that we would have a great deal of trouble from breakage, due to crankshaft vibration. I know that the Rolls-Royce Company did have serious trouble of this kind, and was forced to put a compensating spring drive on the crankshaft gear. I believe that we would have had the same trouble with the Liberty, had the cylinders been placed at an angle of 60 deg., but due to the 45-deg. angle the periodic vibration seems to be broken up to a marked degree.

Digitized by Google

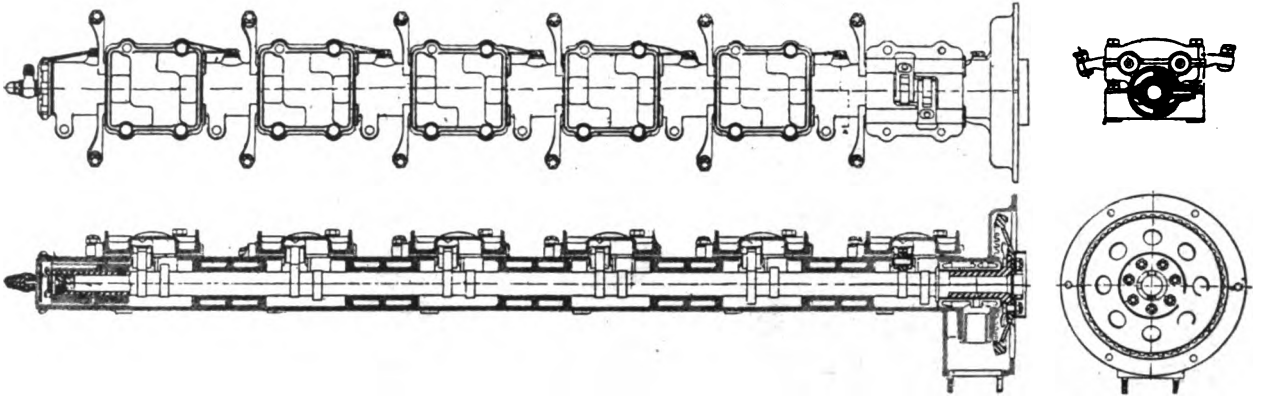


FIG. 6—PLAN AND SECTIONAL ELEVATION VIEWS OF THE CAMSHAFT AND HOUSING ASSEMBLY

Digitized by Google

This could, of course, be proved only by building a sample 60-deg. Liberty, but I firmly believe that the 45-deg. allowed us to get by at this point with the simple light construction.

Lubrication

The double-deck oil-pump and pressed-in oil manifolds are shown in Fig. 5. The crankcase is of the dry type, all oil being returned to an outside tank, cooled and then pumped to the bearings under pressure.

As originally designed, the so-called scupper type of oiling system was provided for the connecting-rod big-end bearings. With this system the crank cheeks are not drilled, but part of the oil which works out of the ends of the main bearings is caught by scuppers or scoops and conducted into the large drilled hole through the crankpin. This system has some very desirable features, among which are simplicity and superior oil economy, and under ordinary conditions it works extremely well, but unfortunately it has one serious drawback. Due to the fact that the large holes through the crankpins are open, all of the oil drains out when the engine is stopped, except in those crankpins which are near the bottom. This does not make much difference in warm weather, as the oil will quickly flow to the ends of the main bearings and be caught by the scuppers when the engine is started, but under cold-weather conditions trouble results, and bearings are liable to be burned out, particularly if the throttle is opened quickly after starting. Since this scupper-feed oil system had been criticized by foreign engineers, we lost no time in changing over to the full pressure-feed system as soon as the first trouble showed up. Comparatively few engines were manufactured with the scupper feed, and so far as possible all light crankshaft scupper-fed engines were kept in this country.

After adopting the full pressure-feed system no further lubrication trouble was encountered, with the exception of over-oiling of the cylinder and fouling of plugs at high altitudes. This trouble was very largely overcome by drilling a hole in the by-pass valve of such size as to lower the oil pressure to about 3 to 7 lb. under idling conditions, and still provide 30 to 40 lb. of oil pressure under full load. This device was entirely satisfactory, with the exception that it varied somewhat with different kinds of oil.

Digitized by Google

At the time the armistice was signed we were experimenting in the air with various kinds of devices interconnected with the throttle to control the oil pressure positively. This is a comparatively easy thing to design, but we wanted to accomplish the result without making any changes in the basic parts of the Liberty engine. Although this device never got into production, I feel that the principle of positively controlling the oil pressure is correct and should be a part of any aircraft engine design.

Cooling System

The construction of the water-pump is clearly shown in Fig. 5. One of the important features of this pump is the automatic spring take-up of the two stuffing-boxes, one of which seals the oil in the engine and the other the water in the pump. This construction proved very satisfactory. From an installation point of view, the water-pump is located in rather a bad place and experience seems to indicate that the best practical place to locate the water-pump is at the bottom of the crankcase near the rear end, in a vertical position, as on the Hispano-Suiza aircraft engine. Nothing which ever has to be got at should be placed on the rear end of an aircraft engine, as it is often desirable to locate the engine just in front of a permanent bulkhead. To have located the water-pump as suggested in the Liberty engine it would, of course, have been necessary to have a different arrangement of the oil-pump. The Hispano-Suiza oil-pump is a very satisfactory arrangement, but I prefer that the oil-pump be placed so that it can be reached from the bottom or one side of the crankcase, without disturbing the water-pump or any other accessory.

Many rumors have been circulated that the Liberty engine is hard to cool, but this is not and never was a fact. We did have two difficulties in connection with cooling the Liberty engine, one being that of the difficulty which we had in obtaining good tubular radiators, and the other that involved in working a 400-hp. radiator into the design of a plane which had originally been laid out for 240-hp. We were handicapped by not knowing just how much radiation to provide, as there is a great deal of difference between cooling an engine on the ground and at 10,000 or 15,000 ft.

We finally adopted the British practice on radiators,

Digitized by Google

as follows: All radiators to be of the tubular type with the ratio between the inside diameter of the tube and its length 1 to 12 desired, and from 1 to 10 to 1 to 14 permissible; the size of the radiator to be determined by the horsepower output on the climb, 0.7 sq. ft. of wetted surface per hp. output being the desired figure. The area of the wetted surface is determined by calculating the outside surface of the tubes, nothing being deducted for the short space taken up at each end by solder:

$$\frac{\pi d l n}{144p} = 0.7$$

Where d = outside diameter of tube in inches
l = length of the tube in inches
n = the number of tubes
p = horsepower on the climb

This formula has been extensively used, and a radiator designed in accordance with it will give perfect satisfaction on any well-designed aircraft engine, provided the radiator is well made, properly located, and the air-flow through it is not badly choked by obstructions.

For military work, shutters must be provided in front of the radiator, so that the pilot can close off the cold air and regulate the temperatures at great altitudes, particularly when gliding in cold weather.

Ignition

Figs. 2 and 5 show the arrangement of the ignition generator, as well as the ignition heads of the Liberty generator type of ignition. The small 10-amp.-hr. battery used in connection with this system can be located in any convenient place about the plane, and the double ignition switch is, of course, placed at a convenient point on the instrument-board.

At the time the Liberty engine was designed, so far as we knew no reliable light-weight twelve-cylinder magnetos were in existence, and we did not want to follow the foreign practice of using four six-cylinder magnetos, not only because of their weight, but also on account of

Digitized by Google

the weight and complications of the necessary drives. Mr. Hall and I had both had extensive experience with the generator type of ignition on aviation engines, and knowing that a light-weight reliable outfit could be secured, we deliberately incorporated it in the design, although we anticipated that we would meet with stubborn resistance from people who had not had experience with this type of ignition. The design, as originally laid down for this engine, proved to be exceedingly satisfactory, and very few changes were made during the early experimental stages.

As indicated in the drawings, an ignition distributor head complete with a coil located at the rear end of each camshaft housing; each one of these heads is cross-wired so as to make it possible to secure ignition in twelve cylinders on either head, thus providing a complete double system.

One of the very desirable features of the Liberty engine which is directly traceable to its ignition, is ease in starting, it only being necessary to pull the engine over very slowly to start it.

My experience would indicate that with a large-bore engine it is much better to start by pulling it over slowly than on the spark with the starting magneto or vibrator. I believe this is due to the fact that to start on the spark it is necessary to have the mixture just right and on the rich side, and where several attempts are made to start from the spark, excess gasoline often accumulates in the cylinders and cuts the oil off the pistons, due to the large clearances. This is apt to result in scored cylinders.

I think the principal objection to the Liberty ignition system is the location of the ignition heads. They were, of course, placed in their present position to obtain simplicity and light weight, but in some installations they are in the way of a permanent bulkhead, and would be better located if placed at the side. It would, of course, add something to the weight to place them anywhere else, and this is a factor which would have to be taken into consideration. Since the Liberty engine was designed, some excellent twelve-cylinder magnetos have been developed, and it is entirely possible that in laying out a new design at the present time a magneto installation might be provided which would be just as light and just as reliable as the generator type used on the Liberty.

Digitized by Google

This is a matter which would have to be proved by actual design and exhaustive experimental work.

Carburetion

At the time the Liberty engine was designed, the only proved-out aircraft carbureter available in this country was the old-style single-venturi Zenith, and, although we

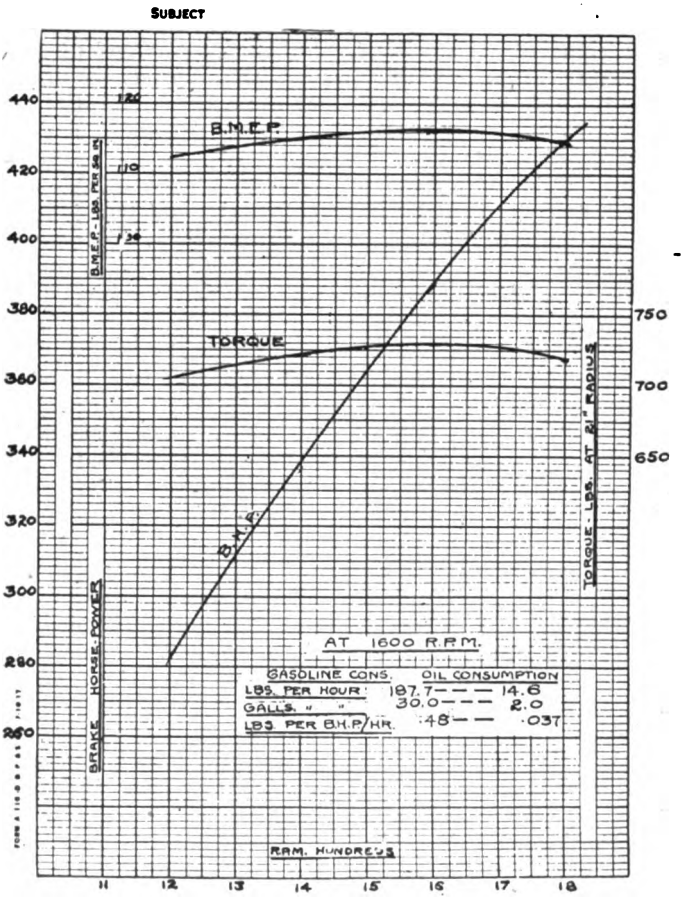


Fig. 7—Average Characteristic Performance Curves of Well Worked-in Twelve-Cylinder Liberty Engine

Digitized by Google

knew that this carbureter would not be entirely satisfactory, we had to specify it until such time as we could get definite information on something better.

Figs. 1, 4 and 5 show the arrangement of the Zenith carbureter, the intake header and water outlet arrangements. It will be noted that four intake headers are used, each serving three cylinders. It will also be noted

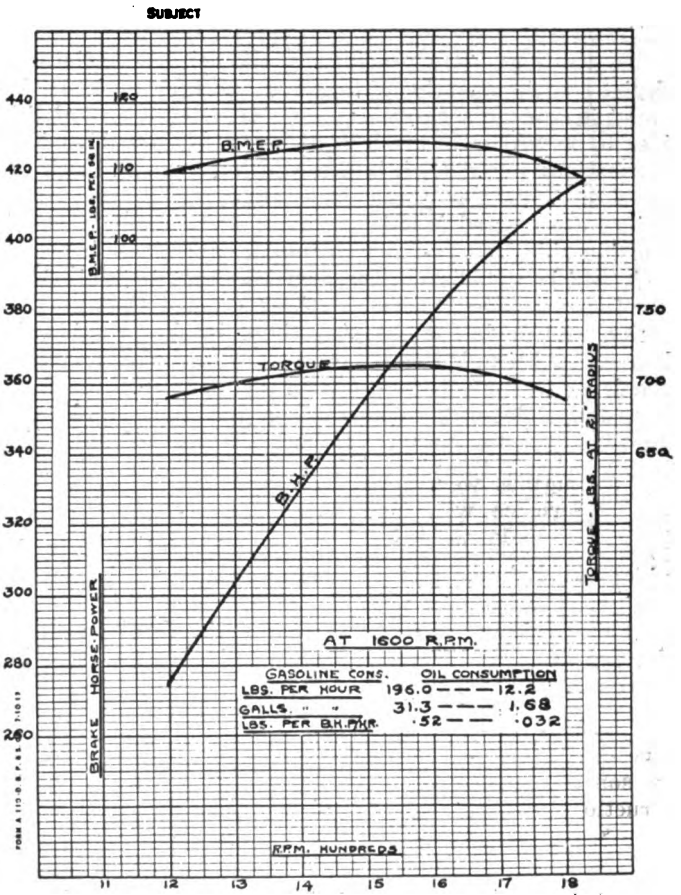


FIG. 8—AVERAGE CHARACTERISTIC PERFORMANCE CURVES OF TWELVE-CYLINDER LIBERTY ENGINE AS DELIVERED BY BUILDER

Digitized by Google

that hot water is taken out of the top of the cylinders into water-jackets on top of the intake headers and piped from there to the radiator inlet. This arrangement of intake header proved very satisfactory, and resulted in very good distribution at all altitudes. It will be noted that the throttle-valves in the carbureter were arranged fore-and-aft, instead of crosswise, to prevent interfering with the distribution under throttled conditions. This arrangement proved very satisfactory. The altitude adjustment originally provided on these carbureters had very little effect on the mixture and was, therefore, unsatisfactory.

No strainers were provided in the original carbureter design, as it was thought that a strainer could be located in a more accessible place. Experience proved this idea to be wrong, as small particles from the rubber hose connections would work into the carbureter and block the nozzles. This was particularly annoying, as the carbureters are located in an inaccessible place, and it was a considerable job to remove the nozzles and clean them out.

It will be noted from the drawings that individual air scoops were fitted to each carbureter, and that no provision was made for carrying these intakes outside the bonnet. Although these scoops were drained overboard, the drain was effective only with the plane level or climbing, and a flooding carbureter on the glide would spill gasoline over the engine. If backfire occurred after this had happened, the plane might be set on fire. As soon as the engines were received overseas where they had had experience with fires, various modifications were promptly made to reduce the fire hazard, before the planes were flown, and we were requested to change the design as quickly as possible, to overcome this trouble.

While making a change to reduce the fire hazard, we decided to alter the altitude control also and provide screens at the carbureter and beyond all hose connections. Figs. 9 and 10 show the revised construction, which it was intended should be in all production Jan. 1, 1919. The change in the altitude adjustment consisted simply in some rearrangement of the passages, and the construction, as finally worked out, was so simple as to make it possible to make this change in the field. To provide for a screen, a small aluminum casting *I*, Fig. 9, was provided, and arranged so that it would screw on the old carbureter. This casting was provided with a nipple to

Digitized by Google

receive the gasoline hose connection, and the screen was easily removable by taking off the nut *J*.

To prevent the possibility of fire, the individual air intakes were removed from the carbureter, as well as

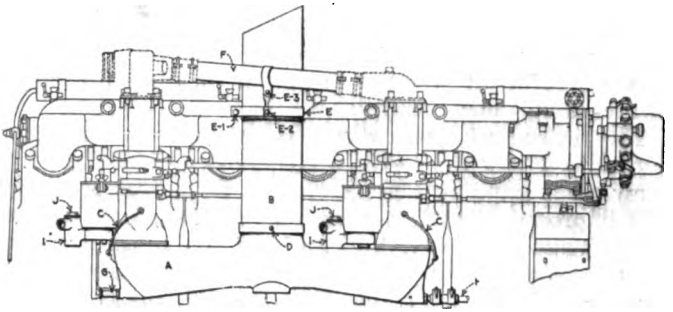


FIG. 9 — LONGITUDINAL ELEVATION SHOWING REVISED CARBURETER ARRANGEMENT

their retaining springs, and a single long intake *A* was provided and held on by spring bails *C*. This intake was machined at its center to receive a large single intake pipe *B* extending up through the center of the engine and out through the bonnet. The top end of this pipe was cut off at an angle of 25 deg. A dowel *D* engaged a slot in the intake pipe *B* and prevented it from turn-

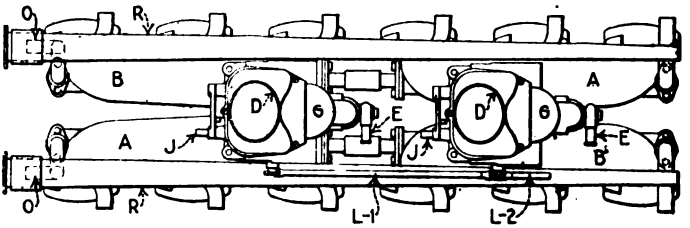


FIG. 10—PLAN VIEW OF REVISED INTAKE-HEADER ARRANGEMENT

ing. A clamp band *E* and E_1 was arranged to anchor the intake pipe *B* to suitable cap screws already existing in

Digitized by Google

the intake headers. The fragmentary plan view, Fig. 10, shows this rearrangement and the way it is necessary to bend the water outlet pipe to permit the installation of the new intake pipe *B*. The intake header *A* is provided with nipples *G* at each end, so that overflow pipes can be attached and carried outside the fuselage. It is obvious that this provides for the complete draining away of all stray gasoline, whether the plane is climbing, diving or flying level. This new arrangement of altitude control, carbureter screen and intake pipe, has been extensively tested out in the air, and has proved to be exceedingly satisfactory.

The revised altitude control was worked out first and went into production in the early summer of 1918, and it is my understanding that all engines were equipped with this improved altitude control before being used at the front. Vague rumors to the effect that the Liberty engine has excessive gasoline consumption have been pretty generally circulated, and this, of course, if true, would be serious. It is obvious that all other things being equal, the gasoline consumption of the engine will be in proportion to the horsepower developed. All well-known aircraft engines at the present time have about the same gasoline consumption per horsepower-hour. This runs from 0.48 to 0.56 lb. per b.hp.-hr., depending on conditions. In this respect the Liberty engine is no better, and no worse, than other well-known designs.

Running wide open near sea level, the Liberty engine will develop 400 to 420 hp. and granting that it develops the average, that is, 410 hp., and that the average service conditions maintain, it will probably have a gasoline consumption of 0.52 lb. per b.hp.-hr. Under these conditions it would burn 213.2 lb., or approximately 35½ gal. per hr. The same engine flying wide-open at 15,000 ft. would be developing approximately 295 hp. and if the altitude adjustment was properly used, the gasoline consumption would be reduced in approximately the same ratio. This would bring the consumption down to 153 lb., or roughly 25½ gal. per hr. As a matter of fact, however, the general practice is to throttle down, except for short periods of time when it is desired to obtain maximum speed. Where a plane is capable of making 120 miles per hr. at 15,000 ft. altitude, it is good practice to throttle down to between 90 and 100 miles, thus enormously reducing the horsepower and gasoline consumption per

Digitized by Google

hour, without seriously affecting the distance traveled. We know from practice that with a Liberty Twelve mounted in a DeHaviland Four or Nine plane, we can average about 100 miles per hr. in cross-country flying at 15,000 ft. on 20 to 22 gal. of gasoline per hr. Throttling down still more will further reduce the gasoline consumption, and it is possible to fly a DeHaviland Liberty-equipped plane at about 75 miles per hr. on 17 gal. of gasoline per hr.

Figs. 7 and 8 give absolutely accurate data as to gasoline and oil consumption of Liberty engines running wide-open at 1600 r.p.m. near sea level.

A rather radical carbureter design, which was worked out for the Liberty Twelve, while only used experimentally, gave some very promising results. Fig. 11 shows this experimental carbureter and intake-header arrangement, and Fig. 12 is a fragmentary plan view showing the same arrangement. Fig. 13 is a diagrammatic sectional drawing, showing the principal parts of the experimental carbureter. It will be noted that two carbureters are shown, as in the standard Liberty, but they are what might be called an inverted type. Without going into detail as to the construction of this carbureter, it will be noted that the double-venturi arrangement, which has been highly developed during the war, makes this construction possible. The reason for this is clearly shown in Fig. 13. It will be noted that this type of carbureter cannot flood into the engine, as would be the case in the ordinary type of carbureter turned upside-down. In Fig. 13, *D* is the needle-valve float, *Y* the drain compartment

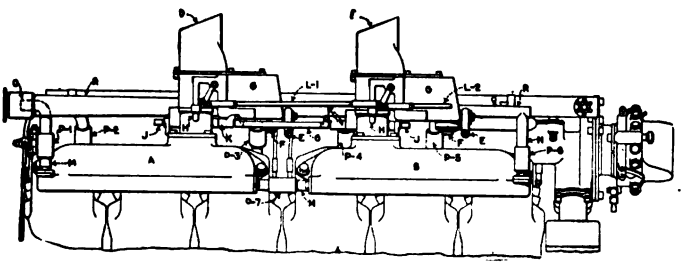


FIG. 11—LONGITUDINAL ELEVATION SHOWING EXPERIMENTAL CARBURETER AND INTAKE-HEADER ARRANGEMENT

Digitized by Google

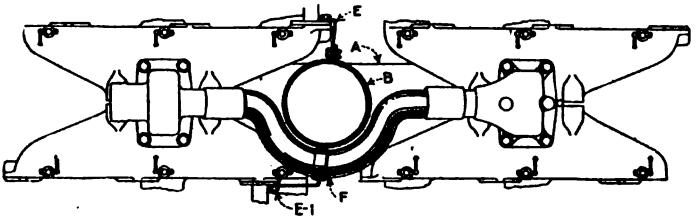


FIG. 12—FRAGMENTARY PLAN VIEW SHOWING EXPERIMENTAL CARBURETER AND INTAKE-HEADER ARRANGEMENT

connected to an overflow pipe, *K* the altitude valve, *F* the jet, *N* the compensator well, *M* the compensator feed holes, *I* the compensator, *L* the idling mixture passage, *O* the passage to the secondary choke, and *P* the secondary choke. This arrangement is very desirable for airplane use, as it provides short separate intakes from each carbureter that project directly out through the bonnet and make fire from backfire impossible. Another important advantage of this arrangement is the matter of accessibility, as the carbureters are right up on top of the engine where all connections and adjustments can easily be got at, and it leaves the V between the cylinders absolutely clear for machine-gun installation.

It is obvious that this type of carbureter requires a different kind of intake header, and as designed for the experimental job there were rights and lefts, as shown by *A* and *B*. This construction made it necessary to change the water outlet headers, and provide a separate outlet manifold *R* for each line of cylinders. On account of the gas impinging against the bottom of the header in this construction, it is necessary to place the water-jackets on the bottom of the intake headers, and to get hot water into these jackets, a connection was made at the rear end through the water outlet manifold *R* by the pipe *N* and hose *P*-6. The jackets were connected at the center by the nipples *M* and hose *P*-7. At the front end the jackets were connected to the water manifold *R*, by the nipple *M*, hose *P*-1 and pipe *O*. This pipe *O* was arranged to extend inside and then turn forward with the flow to form an ejector and thereby induce some of the hot water to flow through the jackets. This construction worked out very satisfactorily and the intake header seemed to keep just as hot as in the standard Liberty construction.

Digitized by Google

As stated above, this whole inverted carbureter arrangement was treated as a purely experimental proposition, as it was recognized that it would be impossible to put it into production, owing to the fact that absolutely new carbureters would require new tooling-up, as well as many other small parts. I believe, however, that all those who have tested this arrangement believe it to be the best possible installation for the Liberty engine. This carbureter arrangement has every advantage of all such arrangements that I know of combined, with one exception; it does not provide for gravity feed.

Angle Between Cylinders

The Liberty engine has been criticised on account of its cylinders having been set at an included angle of 45

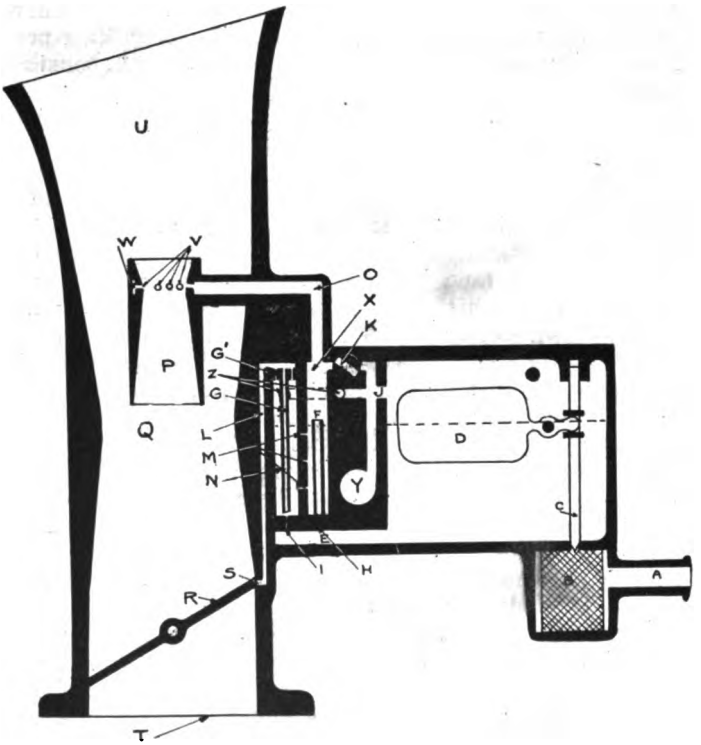


Fig. 13—Diagrammatic Sectional Elevation of Experimental Carbureter

Digitized by Google

deg. All experts in engine design know that a six-cylinder engine is perfectly balanced. Two six-cylinder engines hooked to the same crankshaft are also perfectly balanced at any angle, except as to impulse frequency. Before designing the Liberty engine I had experimented extensively with various angles of cylinders, and knew that the 45-deg. arrangement would not be objectionable, so far as lack of smooth running was concerned, and that it had distinct advantage, not only in that it reduced heat resistance, but also that it reduced synchronous vibration of the crankshaft, due to the breaking up of the evenly spaced impulses.

The cover over the oil-pump in the Liberty engine is held on by a spring bail which, while readily detachable, cannot jar loose and come off. This is a well-known mechanical device which has been used for years for exactly similar purposes. This little device, however, has been the subject of widely circulated criticism, and I do not know how much it has cost the Government to investigate persistent criticisms on this device sent in by irresponsible people.

Weight Per Horsepower

I believe it is pretty generally known that the Liberty engine weighs approximately 2 lb. per hp. By using still better materials, making the engine considerably harder to manufacture and lowering the factor of safety, which is pretty high, it would be possible to bring the weight down to about 1.8 lb. per hp. This would greatly increase production troubles, would require more skilled mechanics to keep it in working order, and would, therefore, in my opinion, be an inadvisable move.

I believe that one of the outstanding features of the Liberty engine, as it is now being manufactured, is its reliability. I have flown the Liberty engine thousands of miles cross-country and have yet to make a forced landing. This reliability has, of course, been developed by extensive experimental work in the air and close attention to details of manufacture and inspection.

Reports have been promiscuously circulated that while the Liberty engine has proved to be good for large bombing machines, it cannot be used in a small fast fighting or chasse machine. It was never intended that the Liberty Twelve should be put in a small single-seater

Digitized by Google

chasse machine, and that is the reason the Liberty Eight was developed. It was our original plan to put the Liberty Eight into production and use it for just such small machines, but when our program was finally made up, based on advice from abroad, it did not include a single-seated chasse machine, and for that reason, the eight-cylinder was not put into production at the time. Some four or five months ago it was decided that we should develop a single-seater chasse machine in this country, and the Liberty Eight was promptly brought out and ordered into production. Airplane designers generally agreed that the Liberty eight-cylinder engine, developing 300 hp. and weighing approximately 600 lb., will make a very satisfactory powerplant for a plane of this type.

Air Performance

Owing to the fact that the performance of an airplane must be measured in the air, it is rather an involved matter to make a full-flight test requiring, as it does, a number of special instruments, a well-qualified pilot and proper technical experts to make the necessary corrections for temperature, air density, etc., after the readings have been secured. When we first started making full-flight tests in this country, we did not have the proper equipment, and a number of tests were made and reported, which were not on a comparative basis with similar tests of allied planes made in Europe. Quite naturally this has led to a misunderstanding, and it has been claimed that the DeHaviland-Four plane equipped with the Liberty engine, is not as good as allied planes equipped with engines of much less horsepower.

To throw some light on this subject, I am giving below a few comparative figures covering foreign planes. They give average performance of three well-known planes, namely, the French Salmsom 270 hp., English DH-4, using the Siddeley 240-hp. engine, and the Italian Pomilio E, using the Fiat 240 hp. The USDH-4 is, of course, equipped with the Liberty Twelve. The figures on allied planes were secured from official technical reports from abroad and figures on the USDH-4 were taken from tests made by the Technical Section of the Department of Military Aeronautics and the Engineering Division of the Bureau of Aircraft Production.

Digitized by Google

OBSERVATION PLANE

	Average Foreign	DH-4
Power, hp.	266.6	400
Speed at sea level, m.p.h.	116.8	128
Climb to 10,000 ft.	9¼ min.	7½ min.
Ceiling, ft.	20,267	21,000
Endurance (cruising)	3½ hr.	4⅓ hr.

DAY BOMBER

Power, hp.	266.6	400
Speed at sea level, m.p.h.	110.5	118
Climb to 10,000 ft.	11¼ min.	11 min.
Ceiling, ft.	16,000	17,500
Endurance (cruising)	3½ hr.	4 hr.
Bomb load	423 lb.	223 lb.

RADIUS OF ACTION, MILES

British DH-9	256
British DH-4	244
Breguet	151
USDH-4	310

In the above comparison it will be noted that the USDH-4 equipped with the Liberty Twelve shows up well in all cases, except that of the load of bombs carried on a day bomber. This machine was originally designed for a 240-hp. engine and when equipped with a slightly heavier 400-hp. Liberty, plus the necessary gasoline for a larger engine, its carrying capacity is naturally cut down. It was to take care of this work that the USD-9-A was being put into production just as the armistice was signed. This machine has 500 sq. ft. of surface and carries 500 lb. of bombs with practically the same performance as the USDH-4. In addition to the USD-9-A, the following planes were being put into production at the time the armistice was signed:

VE-7 advanced training machine, equipped with 150 hp. Hispano-Suiza

Le Pere two-seater fighting machine, equipped with the Liberty Twelve

Glenn Martin day or night bombing machine, equipped with two Liberty Twelves

U. S. Bristol fighting machine, equipped with the Liberty Eight

Many other new types of planes were in the experimental state, including several designs of single-seater

Digitized by Google

fighting machines around the 300-hp. Hispano and Liberty-Eight.

THE DISCUSSION

F. H. TREGO:—The production of our plant was finally transferred to the Ordnance Department. Engines to be used in the large tanks called for in the Allied tank program required some few changes in the design, such as the incorporation of a flywheel and the welding in of a tie between the intake and exhaust elbows to prevent the cracking of the jacket at the top, and this we do in regular production. In connection with the testing of the engines for tank service, the United States Ordnance Department endeavored to comply with the testing specifications as suggested by the British Tank Service, and one of these tests called for four runs of 50 hr. each with wide-open throttle, on dynamometer, at 1400 r.p.m., all parts of the engine being carefully measured before and after each test. Outside of the cracking of the jackets, which was later corrected by the welding in of a tie, we found a tendency of the babbitt to break away from the bronze backing in the connecting-rod bearings in a spot about as large as a ten-cent piece, directly opposite the oil-hole in the crankshaft at the instant of the explosion of the cylinder carrying the plain-end rod. The hole in the crankshaft at this point has a depression on each side of it, leaving the babbitt unsupported for a considerable area and owing to the fact that the plain-end rod which runs on the back of the bronze bushing has 0.005 to 0.0065-in. clearance we decided that a rapping action was set up by this rod on the outside of the bronze and that this continual rapping directly behind the unsupported portion of the babbitt had a tendency to break it away from the bronze. To eliminate this difficulty we had a shaft made up with an oil-hole drilled at a point 30 deg. in advance of the top dead center when the plain-end rod piston is at the outer end of its stroke. Thus a flow of oil on the center line portion of the bearing was assured before the explosion took place. This also provided complete support for the babbitt under the plain-end rod at the instant of the explosion. Tests of this shaft seemed to prove our theory, and we now consider it good practice, even with the single rod, as it assures an uninterrupted bearing surface under the rod at the instant of explosion. We also omitted the depressions on each

Digitized by Google

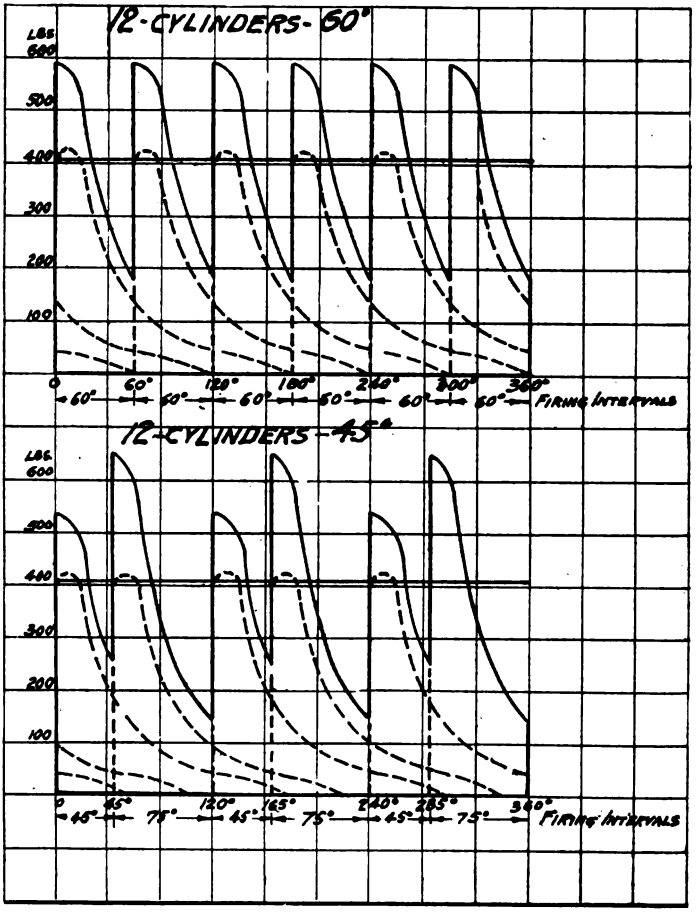


DIAGRAM SHOWING THE OVERLAPPING OF POWER IMPULSES AND IRREGULARITY OF FIRING IN THE TWELVE-CYLINDER LIBERTY ENGINE

side of the drilled hole and simply broke the sharp edge of the hole. After a test of 46 hr. under full load at 1400 r.p.m. the bearings were found to be in excellent condition.

T. S. KEMBLE:—The Liberty aircraft engine stands as a monument to the daring, courage and cooperation of the engineers, manufacturers and all who had a part in

Digitized by Google

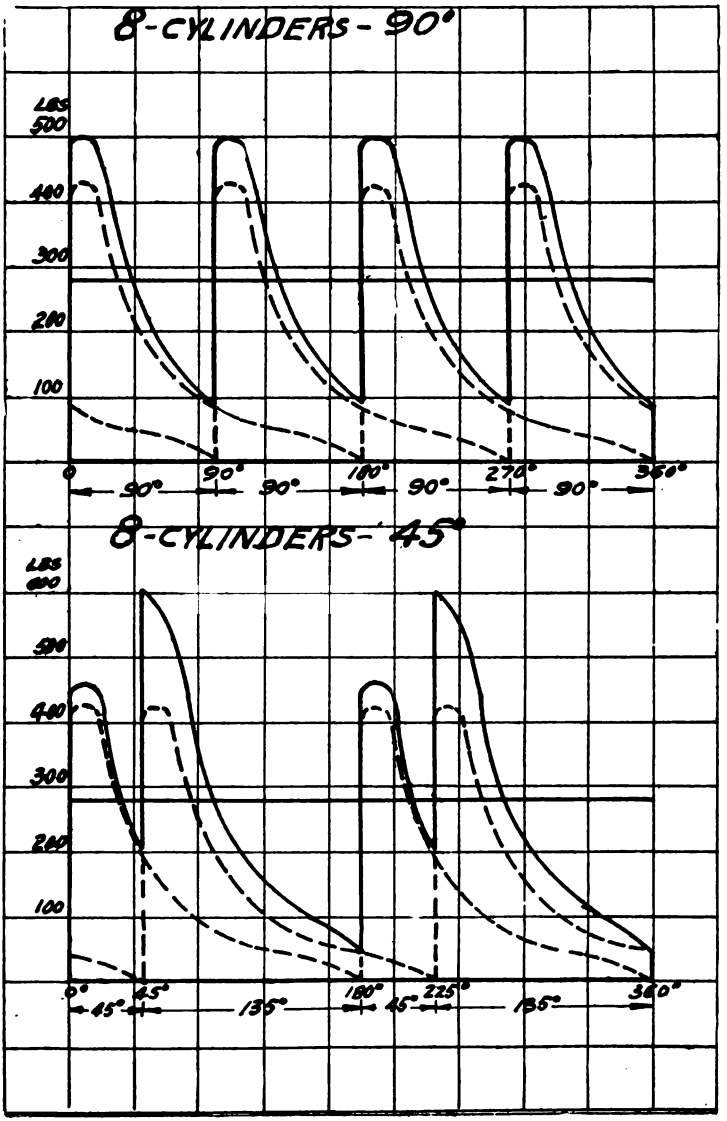


DIAGRAM SHOWING THE OVERLAPPING OF POWER IMPULSES AND IRREGULARITY OF FIRING IN THE EIGHT-CYLINDER LIBERTY ENGINE

Digitized by Google

the program. The first engines were completed in phenomenally short time. Production, already gratifying, was growing rapidly when the armistice was signed. Delays caused by necessary alterations in design occasioned no surprise to those in private enterprise who were already familiar with the difficulties involved.

With the war apparently ended, the necessity for tremendous production in aeronautics has ceased, Government orders have been cancelled wholesale and the entire industry pauses to catch its breath, consolidate its organizations and alter its course to meet the new conditions. Only short-sighted blundering on the part of the industry and of the Government could cloud even the immediate future under these new conditions, for the problem of adapting recent progress to commercial purposes is remarkably simple, and we have enough men of clear vision to make the application rapid. The present knowledge of the art, together with the foresight and courage of engineers and business men, assures immediate prosecution of commercial development, which, beginning somewhat slowly, will gather momentum rapidly.

Many of us believe that our military authorities now realize thoroughly how exceedingly temporary is the standardization of aeronautic engines and planes and that they will give substantial encouragement to development by private enterprise of those vast improvements over all their present types which are necessary to keep abreast of the times. Even before the armistice, privately developed planes had shown performance far in advance of those possessed by any of the Allied forces, and these are only a foretaste of what is to come.

Let us as Americans and engineers give serious consideration to the fact that, if another unfortunate war should arise, the initial and perhaps the final advantage in that conflict will lie with the nation which has attained the highest development in aeronautics. Our country, with its broad areas and its vast industrial development, can obtain the lead more easily than any other.

H. E. MORTON:—It is nearly always true that the user must decide the requirements, and, as the Government is the customer, so far as military aircraft equipment is concerned, I maintain that the only reason we were unprepared or behind the world in airplane engine design, was the fact that we were working to specifications which were suited possibly for commercial aircraft, but not for

Digitized by Google

military machinery. The Packard engine, together with practically all the other American engines available in early 1917, were in what is now the heavier class. Of course, the Technical Section of the Department of Military Aeronautics now has complete data on military aircraft requirements. If this section will keep such data up to the minute and in such shape that they can be studied at any time by accredited engineers in the industry, I know the engineers will gladly cooperate.

The phenomenal development of the Liberty engine was made possible only through the possession by its designers of the latest information on requirements. Similarly when, at a meeting in Washington of the Manufacturers' Aircraft Association with the United States and foreign representatives, it was stated the engines must not weigh over 2½ lb. per hp., and tests would be modified accordingly, work was immediately started on such engines. This meeting took place in May, 1917, and in just 10 weeks the Sturtevant 210-hp. engine, weighing 500 lb., or 2.38 lb. per hp., was flying daily. This is merely cited as another illustration of what can be done when the requirements and limitations are known.

Although there are double breakers, coils and distributors, is the ignition a double system since it depends on one generator for energy, while running, and one battery when starting? It would seem as though this was putting a great deal of responsibility on the storage battery in case of a stalled engine away from a supply base.

CHARLES B. KING:—This country was building two types of aircraft engines which were used at the front prior to the development of the Liberty engine. These engines were the Gnome and the Hispano-Suiza. The French Section Technique Report No. 98, November, 1917, was issued about 6 months after the start was made on the Liberty engine and gives the weight of the Lorraine-Dietrich engine bare as 606 lb., an increase of 78 lb. over the figures given Col. Vincent; also the weight of the engine complete with radiator and water was given as 769 lb., or an increase of 98 lb. This increase may have been due to later structural changes. This engine was of the eight-cylinder type with cylinders set at 90 deg. A few of these engines were built and put into service late in 1917.

A few days after the design work had started at Washington, at a late supper at the New Willard Hotel, I suggested to those present that the name Liberty engine be

Digitized by Google

adopted. This suggestion was very well received and the next day I passed the title along, and in each instance it was endorsed and seemed to be adopted almost at once. It is quite possible that Admiral Taylor may have made the title official at one of the Aircraft Board meetings. Col. Vincent at this time was in the employ of the Packard company and later came to me saying that he did not want to do anything about the name until he had taken it up with his directors.

I agree with Col. Vincent that anything under 2 lb. per hp. is not desirable, my firm belief being that something over that figure stands for less vibration and longer life. It takes a certain mass to absorb the explosive effect, and the commercial engine of tomorrow will be of considerably more weight per horsepower.

The Liberty Eight will be a less successful engine than the Twelve, owing to the 45-deg. angle between cylinders. The lapping of power impulses and the irregularity of firing are apparent from a study of the accompanying diagram, the firing order being 45-135-45-135. The vibration of this engine in a plane will be quite marked.

Digitized by Google

MAKING THE AIRPLANE A UTILITY

By Grover C Loening[1]

THE author's views on the future of the airplane in peace are outlined. A brief history of airplane achievements and the great advance in airplane construction is given; what is required for commercial success is then discussed.

Owing to the great expense incident to its use, the airplane must offer very decided advantages that cannot otherwise be obtained, and its dangers and uncertainties must be overwhelmingly outweighed. In the appraisal of the real value and possibilities, its use as a popular means of diversion is eliminated. Speed is the only advantage the airplane has over the automobile, railroad and steamboat. At present, owing to the limited number of airdromes and the fact that these are somewhat isolated, the time between cities by airplane is hardly less than by train. With an airplane speed of 70 m.p.h., even under ideal atmospheric conditions practically no time would be gained in traveling by air from New York to Washington; but at 170 m. p. h., only about one-half the train time, with practically no greater risk and less fatigue, is required.

How speed can be attained is then considered. The history of speed in airplanes has been a see-saw between improvements in the plane structure and in the engine, experience showing that for an improved engine a suitable plane structure can readily be designed. A proper engine, therefore, is what is principally needed to make the airplane a peace-time commercial success.

With considerable technical detail the required improvements in engines such as greater power, less weight and better adaptability to the airplane to present the least air resistance are outlined. Such improvements, deemed entirely feasible, with the addition of a closed passenger car offering added protection against air-travel discomforts, will result in attaining the maximum value of the airplane in peace.

The pages of glorious history of the military airplane have practically been written, and contain not only reports of the countless wonderful exploits of heroism and

[1]Consulting aeronautical engineer, Loening Aeronautical Engineering Corporation, Long Island City, N. Y.

Digitized by Google

super sangfroid of the airmen, but also more prosaic accounts of quantities of airplanes and engines delivered, of millions of hours of flying, and here and there of instances of cleverness and ingenuity in engineering that gave the airmen high-performance steeds of incalculable advantage.

We turn over a new leaf now to the peace airplane, and are all seeking on blank pages the answer to what it will be, because the commercial peace-time airplane has not yet been under serious and continued development. It is a fact, generally apparent, that the most brilliant minds in aviation, both here and in Europe, for over 10 yr. have been giving to their developments in airplane engineering a wholly military consideration, and whether consciously or not, have educated themselves and their industry so definitely along these lines that the dawn of a new era requiring special development of its own is practically at hand.

No Retrogression to Pre-War Status

Aeronautics will not revert to the status it had prior to the great war. No change in governments is apt to be more radical than the revolution in the attitude of the public and of business interests toward air travel that can be brought about by intelligent effort.

A great knowledge has been acquired on the scientific and practical aspects of airplane design and construction —an available mass of data forced into being by the pressure of war—and by virtue of the necessity of cooperation and of general dissemination for war purposes, these technical data are more generally available, and better, more elaborately, recorded by Government departments than could possibly have been done by scattered individual efforts. In this the war has been an asset. Not only are there technical data; much has been learned and recorded on the cost of upkeep of airplanes, the hours of flying a machine can be expected to give and the percentage of good flying weather in various localities. More than that, thousands of men have flown, have realized the limitations of flying, and have passed out of the stage of glamour and misguided "enthusiasm" to a more hard-headed and far more valuable understanding of aviation as it is—not as they would have dreamed it ought to be.

It is a peculiar fact, as evidenced by false starts made year after year, that the aeronautical industry prior to

Digitized by Google

the war suffered greatly from the setting up of impossible rainbows to be chased after; resulting merely in repeated demonstrations that the aircraft business was "flighty," uncertain, and decidedly unstable. The war, with its censorship, has greatly limited this, but above all has reduced the size of the over-credulous public, at least by the 200,000 or 300,000 persons who directly or indirectly have cut their eye-teeth on the airplane business.

The commercial possibilities of flying, and means, definite and well-planned, to develop them, can be translated today into a sound, level-headed business, because we have very definite knowledge, worth untold millions of dollars, upon which to base a mature, well-founded judgment. To be successful commercially, the airplane must be made to offer very definite advantages that cannot be obtained by other means. Its peace-time raison d'etre has to be based on qualities and performances so striking that any obvious disadvantages of high expense, danger and uncertainty will be overwhelmingly outweighed. To ignore the disadvantages and the serious limitations that we know exist is merely an invitation to lose the confidence of the public, when, sooner or later, these features become evident. In other words, it is far better to complete a 100-mile flight with a 200-mile radius airplane than to have it fail in a 300-mile attempt.

Let us, therefore, give consideration, brutally frank, if necessary, to the real value and possibilities of aircraft. To begin with, is it really a pleasure to fly? There are many varying opinions, but there is general agreement on these points: The noise of the engine and propeller are decidedly disagreeable; the general nature of flying, even as a passenger, uses up nervous energy, making long trips tedious and uncomfortable, and there is a disappointing absence in flying of the sense of buoyant exhilaration which almost every one looks for on his first trip. Airplanes are very material, their vibrations are very evident, their grip on the air almost ferocious, and frequently oil, exhaust, and the cold rush of air add to a feeling of utter subordination to a mechanical power. No one likes the bundling up and goggling up ordinarily required for flying; neither is it agreeable not to be able to communicate freely with one's passengers without the aid of telephones. On the other hand, we have the pleasure of the marvelous views to be had from aloft on a clear day, the feeling of mastery that the pilot

Digitized by Google

has over the craft he can so easily direct in three dimensions, and not only the delightful technical interest that many take in flying, but the pleasure that a few very expert pilots find in stunting an airplane—not unlike cutting fancy figures in skating.

Many of the disagreeable features of flying will be overcome by better protection from wind, noise and oil, and by closed-in bodies, and careful provisions along this line will find their way into all new types of airplanes. But the fact remains that while mere flying around a field is a pleasure to some, it is by no means proved that it is sufficiently so to become a universal sport. Something more is needed, some feature of utility that will make the physical aspect of flying secondary. The New York subway is admittedly a disagreeable place. The air is bad, the crowded cars uncomfortable, the noise deafening; and yet how many millions of people use the subway, many abandoning their motor cars, because of its great utility, speed and time saving?

Has not the tremendous development of the automobile been due rather to its utility than to the mere pleasure derived from riding about in it? When the automobile became a time saver and an exclusive conveyance, absolutely under the command of its owner, with no schedule but his will, its utility and convenience far outweighed mere pleasure driving, as is evidenced, for example, by the increasing popularity of the closed cars, where the open-air pleasure element is entirely subordinated to the convenience of the vehicle for transportation alone.

Airplane and Automobile Not Competitors

The airplane cannot hope, for the present, to cope with the automobile for short haul, with the motor car's ability to make of every curbstone a landing field; but the automobile as a conveyance ceases to show its great advantages over distances greater than 50 or 60 miles. It is here that the airplane can come in and begin to offer a feature of real utility—a conveyance, exclusive and capable of a longer distance radius. But as soon as it does so it obviously competes with the railroad train and the boat.

The automobile has already very seriously cut into the suburban trolley business, as is evidenced by numerous reports on the subject recently issued. How can aircraft as a means of transportation seriously cut into railroad

Digitized by Google

TYPICAL FAST BIPLANE IN WHICH THE SHAPE OF THE ENGINE NECESSITATES A LARGE RADIATOR AND FUSELAGE

Digitized by Google

traffic, despite its higher expense? It can obviously offer higher speed in miles per hour, but how much higher must this be to overcome ordinary winds, and to offer less actual time in travel, not in miles per hour, but from office door to office door?

We are at once faced with this curious situation—that the speed requirement for successful commercial aviation is more important today than it will be several years from now! This is because airdromes are less frequent and more remote from cities, and the office-door time interval must include a motor-car ride to the airdrome, and this is likely to be far longer than the taxicab ride to the station.

Speed is needed at the very outset to give to aircraft travel the element of real sound utility, offering so much of advantage that people will ride in airplanes, not because of the sensation, or the stunt of flying, but because, despite the danger, the uncertainty or the expense of flying, it is overwhelmingly the fastest and most direct way. When we get to this point a commercial era as big as railroading begins to rise out of the fog.

The significance of higher speed is readily shown. A 70 mile per hr. airplane, with no allowance for head winds, would take about 3½ hr. to go from Belmont Park to Anacostia Field, near Washington. From the office door in New York to Belmont Park would take about 50 min., and from Anacostia to the Washington office door about 30 min., making a total of 4 hr. and 50 min. under perfect conditions and connections, a total certainly not enough less than the train time to give any justification for the added expense and bother. But the 170 mile per hr. airplane would go from Belmont Park to Anacostia in 1¼ hr., a shorter and therefore a less wearing trip, and with the same connecting trips to offices would give a total of 2 hr. and 35 min. from office door to office door—less than half the train time. A business man could leave his house at 8 a. m., arrive in Washington at 10.35, leave Washington at 2 p. m., and arrive at his office at 4.35. Now, as will happen, let us consider a 20-mile head wind. The 70 mile per hr. machine will take about 4½ hr. for its flight, making a total of almost 6 hr., longer than the train; while the 170 mile per hr. airplane will make its flight at 150 miles per hr. in 1 hr. and 28 min., giving a total of 2 hr. and 48 min. Obviously, therefore, the fast machine is less dependent on the weather. In addition, it is less wearing on

Digitized by Google

the engine, due to the shorter duration of its run.

The element of safety, compared with the train, is questionable and yet to be proved. There are many train accidents. The unreliability due to weather is caused principally by fog, since an airplane is not stopped by rain, particularly with a closed body. Enough must be offered to overcome objections.

Our needed utility, then, is clearly speed. Whether large or small machines are used is really subordinate. *They must be fast machines.*

Practicability of High Speeds

How practicable is higher speed in airplanes? A three-seated monoplane recently in test at Dayton, made 150 miles per hr. A European scout is reported to have made 160 miles per hr. The standard DeHaviland makes about 120 miles per hr.

Increase in speed of airplanes is limited by

(1) Landing field conditions requiring a certain minimum speed for safe landing. In general, today, an airplane for practical purposes must be able to slow down to at least 55 m.p.h.

(2) The speed-range value of wing sections, sufficient area having been provided for the necessary slow speed, with available range up to maximum high speed. This depends much on the wing section used. Wing sections are now available that permit of a speed range of as much as 48 to 160 m.p.h. Formerly a speed range of 50 to 75 m.p.h. was considered excellent

(3) The arrangement of wings to give the minimum of interference for high lift at slow speeds and yet also the minimum of area, entering edge resistance and skin friction for high speed. Recent developments have proved the ideal value for this of the monoplane type, since every square foot of its surface is working at the highest possible efficiency, requiring for the same load, a smaller wing of less resistance and less weight

(4) The power of the engine for the same size of engine and of airplane body; obviously the more power, the more speed

(5) The efficiency of the propeller, an increase in which merely means more actual power for the same weight

(6) The structural resistance of the airplane, the air resistance of struts, wires, landing gear, radiator,

Digitized by Google

etc., all of which are a great liability and merely use up power

The history of the increase in speed of airplanes from the early Wright biplane and Bleriot monoplane, that made from 35 to 40 miles per hr., to the present 150 miles per hr. machines, is merely the recital of alternative steps in the improvement of the above mentioned features. Using the same engines, airplanes were made faster by cleaner design, less head resistance, better wing sections. The Nieuport monoplane, which was distinctly an epoch-making design, had almost double the speed of the old Bleriots with the same engines. Then follow the instances where new engines of higher power appear, increasing the speed of the old airplane, followed by a further increase in speed by designing new airplanes for those higher powered engines, and so on, in an endless seesaw of improvement, first on the plane, then on the engine.

One thing is becoming very obvious: With the airplane designing knowledge available, the really fundamental and governing limitation is found in the engine available. The advent of a new engine is quickly followed, now, by suitable planes to make use of it, and the shorter time for development required for the plane is evidence of how much the advance in aviation is becoming essentially a problem in engines, the plane end requiring merely a clever and simple application of what we already know. In this it is becoming increasingly evident that the aeronautical engineer is far ahead of the engines he has available; so much so that a trend of endeavor on his part to include in his work the designing of the engine he needs is almost certain to follow.

The problem of increasing speed divides itself for consideration into two parts: (*a*) How can we increase speed with the present available engines? (*b*) What new developments in engines are needed to give better performance?

The total head resistance of an airplane can be divided into: (*a*) Drag resistance of the planes, a fraction of the lift, (*b*) resistance of the struts and wires supporting the wings, (*c*) resistance of the landing gear, and (*d*) resistance of the body or fuselage, governed largely by the shape of the engine, the size of the radiator, etc.

Digitized by Google

A High-Speed Monoplane in Which the Streamline Shape of the Engine Is Taken Advantage of to Give the Fuselage the Smallest Possible Size

Digitized by Google

The last item, the body resistance, on the usual tractor types is very great; in fact, on a fast machine it is the preponderant resistance, due not only to the bulk of the body, but to the fact that it is placed in the slipstream of the propeller, in an air velocity 25 per cent greater than the speed of the airplane itself. We may look, therefore, to a refinement in the contour of the body, and particularly in a closing up of the various cowling gaps around seats, to reduce body resistance. In considering this it becomes very apparent that the Gallaudet system of propeller drive around the body at the rear, without the awkward structure of the ordinary "pusher" type, has a very real engineering advantage.

The structural resistance of the landing gear is obviously subject to complete elimination by a mechanical method of folding it into the body, as has been proposed by various engineers here and abroad for several years. Struts, and, above all, wires and cables, are being eliminated very rapidly in different modifications that have been developed. Gradually, in reducing the amount of bracing, we are approaching the interior braced wings, which have attracted many designers. A wing structure with somewhat thicker wing sections, requiring no outside bracing, and completely eliminating the structural resistance of bracing struts and wires, has already been built successfully in this country by several people, including myself, and it is found that the weight is not excessive; and the thicker wings, offering room for fuel, radiators, etc., reduce the necessary size of the body and consequently its resistance.

Beyond these features there is not much that can be done with the same engines, except to build the airplane lighter and therefore smaller, and lower in that criterion of performance, low pounds per horsepower.

Improvements in Engines

Turning to our second problem, and seeking improvements in engines, there becomes evident at the outset the real and great importance of the *shape* of the engine. A 400-hp. engine widely used today actually presents, with its necessary radiator, a normal cross-sectional area, at the least, 2 sq. ft. greater than a 300-hp. engine also well known. At 160 miles per hr. airplane speed, practically 200 miles per hr. slipstream speed, this extra 2 ft. absorbs a resistance of

$$KSV^2 = 0.003 \times 2 \times 40{,}000 = 240 \text{ lb.}$$

Digitized by Google

which, at a speed of 160 miles per hr., uses up about 128 hp. Actually, therefore, on the basis of effective power available for speed, the 300-hp. engine of better shape is more powerful, let alone that it is lighter and uses less fuel. Of course, at slower speeds this difference becomes less and less marked, but for higher speed it becomes tremendously important.

Streamline shape, however, is not the only big item in which engines can be improved. Their shape and arrangement for mounting in the airplane are subject to profitable modification. We too frequently overlook the fact that the total weight of an engine is greater than its weight bare. The engine, due to its design, demands a certain arrangement of radiator, a certain cowling, and, what is more important on practically all upright engines today, a heavy, complicated and generally bad design of engine bed. The reason for this is that we are using mostly the automobile type of engine. What we need is an airplane type of engine in which these fundamentals are studied as the important basis for design, and not relegated to be "coordinated" afterward by the airplane constructor. A modification in the engine requiring less in weight of engine bed, or cowling, or doing away with extra fuel-pumps, water headers, etc., offers far easier means of reducing the total weight than lightening of the crankshaft. *It is the total weight of the airplane in the air that counts—not the weight of the engine on the block.*

With the few improvements in reducing airplane resistance incorporated on a 300 or 400-hp., three-seated machine, with a new engine of small size and carefully studied shape, speeds of 200 miles per hr. are actually possible without introducing anything new in the art of flying, or requiring anything more in skill and facilities for landing than we now have.

With speed, airplane navigation itself becomes more sure. A 5 mile per hr. drift throws the 200 mile per hr. airplane only 10 miles off its course in 400 miles, whereas the 50 mile per hr. airplane would, on a 400-mile distance, be 40 miles off its course. And with sufficient speed we have a powerful weapon with which to fight objections of high expense, uncertainty or danger, because not only as the world willing to pay for something it can get in no other way, but the history of every means of transportation shows what inconvenience and bother people will tolerate if their time is actually saved in great enough

Digitized by Google

measure, and their life thereby made more full. In speed is the airplane's greatest utility; let us seek it with every possible intelligent effort.

THE DISCUSSION

J. G. VINCENT:—This paper is very timely, and very much to the point. I entirely agree with Mr. Loening regarding the absolute necessity for putting the airplane industry on a sound footing by a careful and painstaking study of the cold facts. His discussion of the subject is very clean-cut, and worthy of the most careful consideration.

Coming to the matter of design, I note that he lays great stress on the necessity for developing higher speeds by cleaning up the design, improving the engines, etc. Generally speaking, I agree with his contention that reasonably slow landing speeds must be maintained. To put it another way, I would not recommend going after high speeds, at least until proper landing fields are available all over the country.

I heartily agree with him also regarding the necessity for careful study of engine design. I feel certain that aircraft engines can be vastly improved without in any way altering the basic designs which have been found good. These improvements will not only consist of changes to facilitate the mounting of the engine, but also the hooking up of the engine to the various necessary systems, such as the gasoline control, cooling, lubricating systems, etc. The war has taught us the necessity for simplification to secure reliability, and I am sure that if the engine and plane designers will get together they can bring about a wonderful saving in cost and weight and at the same time increase reliability, and therefore the safety of passengers and cargo, to an astonishing extent.

I want to make a strong appeal for increased activity along proper standardization lines. In the war it was necesary to work under conditions which made standardization very difficult, if not impossible, but, as Mr. Loening has stated, a vast amount of data has now become available, and reasonable standardization will greatly facilitate the production of good airplanes during peace times.

A large part of the expense of building airplanes in small numbers is the making of the many small fittings. These are made out of special materials the obtaining

Digitized by Google

and machining of which in small quantities is a very expensive matter. If these parts were properly standardized they could be manufactured in large lots by specialists and made available for the various companies engaged in the manufacture of airplanes and airplane engines.

ALEXANDER KLEMIN:—It is indeed true that the airplane will become commercially useful by virtue of its utility and not because of its pleasure features, and that speed, above all things, is to be desired, but I am not of the opinion that comfort need be entirely disregarded. Mr. Loening deals mainly with the single-engine machine of between 200 and 400 hp., attaining great speed by virtue of refined design and a well-adapted light engine. I think, however, that 200 miles per hr. is slightly beyond our powers at the moment, although this figure can be closely approached. Such a machine could carry one, or at most two, passengers besides the pilot. To secure the required speed the fuselage would, of necessity, be cut down to a minimum cross-section and the passengers closely huddled together. It remains to be seen if this is the most desirable type for commercial passenger service. The expense of operating with a carrying capacity of but one or two passengers would be very great. For a machine of this speed the pilot must of necessity be exceedingly skilful, and he will demand adequate remuneration, while at the same time there will not be many in his class. The engine, if it is to be light, and it must be very light in a small machine of this type, will not have reliability and long life. In the case of engine failure across country the pilot must immediately come down, and for a time, at least, landing fields will be none too plentiful.

It seems to me that we should consider for commercial work the possibility of larger machines with two or three engines. With multiple engines it would be possible to complete a journey with one engine completely out of commission. With the engines set out on the wings, the central fuselage can be made roomy and comfortable and entirely enclosed, with sufficient space for passengers to stretch their legs, an important consideration even on a trip of 1½ hr. The larger machine would be more stable, and thereby safer and more comfortable. The installation of wireless direction finders, the use of maps, the means of communication between pilot and passengers would all be easier. The number of passengers car-

Digitized by Google

ried could be increased, an important commercial consideration. The engine could be more rugged and reliable. It is true that all this militates both against speed and the possibility of landing in restricted areas, but not to a prohibitive extent, and the large machine would certainly cease to roll on the ground sooner than the 200-mile per hr. speedplane. There will undoubtedly be use for both types of plane, but I am of the opinion that the multiple-engine type, making less strenuous demands on the engine builder, is extremely interesting at the present time.

I have studied the question of internal bracing for some time, and agree with Mr. Loening that it offers undoubted possibilities for a small type of machine. For large areas and spans the bridge-type truss will remain. To offset the advantages of internal bracing we have the increased weight of the truss and a poor wing section. A systematic comparative study of the two types will no doubt be made by the laboratories, but the final answer will probably come from the series of machines of this type which are certain to be built.

I am of the opinion that something more than speed and ultra refinement is needed. The airplane must develop on such lines that a little waste here and there need not worry us. For war purposes when expense was no object, skill in handling was presupposed, and a little structural and breakdown risk could be ignored; speed and ultra refinement were certainly the order of the day. We must now build an airplane that can be called a "bus," with all that this insignificant word entails.

Digitized by Google

EXPERIMENTAL AERONAUTICAL ENGINEERING

By Alexander Klemin[1]

A VERY complete technique has grown up in aeronautical engineering and the principles and utilization of this are discussed. However accurate and refined a stress analysis may be, the structure of a machine can be amply strong in its main members, such as spars, wires and struts, and yet fail in the lug of a fitting or the crushing of a bolt. In a machine of novel type an error may creep into the stress anaylsis which will invalidate the strength of even the main members.

It is possible to eliminate much of the uncertainty of structural design by submitting the skeleton of a new machine to a sand test. This and the usual strength testing of airplane parts, such as struts and wires, are the two main tools for investigating strength of structure. Tht French restrict the sand test to the wing truss. In England and America the wings, tail surfaces and controls, the fuselage and the engine mounting are tested. The most important of the tests is of course that of the wings. Lift and drift, the loop, dive and recovery, the spin and the barrel, are analyzed and the method for testing them explained. For tail surfaces fewer aerodynamic data are available. The structure is less determinate, members are small and calculations are apt to be neglected.

Performance can be predicted by wind-tunnel tests. The technique of these is very generally understood. Indeed, so satisfactory and accurate are the results obtained from such tests that experts are inclined to place too much faith in the prediction values obtained from them. If accurate models on the same scale of two machines are tested at the same wind velocity, the better machine can be selected almost invariably.

The difficulties of performance tests now are not in the instruments or the methods, but in the preparation of the plane and engine, and in the work of the pilot. Unfortunately, for a number of points such as maneuver ability, stability and controllability, it is necessary still to rely upon the judgment of the pilot. If, however, the experimental tools available are employed in a skilful manner, according to engineering principles, progress in airplane designing and use becomes a foregone conclusion. Real development is based on patient investigation.

---

[1]Consulting aeronautical engineer and technical editor, *Aviation and Aeronautical Engineering*, New York City.

Digitized by Google

During the war we have seen a tremendous development of the experimental side of aeronautical engineering. Broadly speaking, the construction of every new machine is an experiment even if no systematic tests of any sort are carried out, and the testing is that of usage as in the early days. In a more restricted sense, experimental aeronautical engineering is that technical branch of aeronautics which involves the systematic testing of an airplane or its component parts for the purpose of improvement or innovation, and this from the two main viewpoints of structural strength and performance, stability and controllability. This work, although it may be concerned with the very latest developments, is entirely distinct from the purely aerodynamic research of the physicist. It is engineer's work, and should be carried on by engineers, even though the physicist may have in some cases given the scientific foundation, or helped in devising accurate instruments. A very complete technique has grown up, and it is the principles and utilization of this technique that I shall briefly discuss.

Structural Strength

However accurate and refined a stress analysis may be, the structure of a machine may be amply strong in its main members, such as spars, wires and struts, yet fail in the lug of a fitting or the crushing of a bolt embedded in wood, in which minor details computation may be entirely impossible and judgment alone has to be relied upon. In a machine of novel type, or even one with a slightly varied truss, an error may creep into the stress analysis which will invalidate even the strength of the main members.

At an expense which is negligible when safety is considered, it is possible to eliminate much of the uncertainty of structural design by submitting the skeleton of a new machine to a sand test, in which air and dynamic forces in flight are simulated by the superposition of weights. This, and the usual strength testing of airplane parts, such as struts and wires, are the two main tools for investigating structural strength. In French practice sand testing seems to be restricted to the wing truss. In British and American practice sand testing has come to embrace the wings, the tail surfaces and controls, the fuselage and the engine mounting.

By far the most important sand test is, of course, that on the wings. We have acting on the wings two forces, lift and drift, which have to be simulated by the appli-

Digitized by Google

cation of loads. A difficulty arises in the very enunciation of principles, because we do not know what condition in the air we wish to simulate. Complicated maneuvers such as a spin or a barrel are quite beyond us at the present moment in the analysis of the forces which come into play. We have, therefore, to consider simple maneuvers in one place.

A loop, a steep dive and a sharp recovery from a steep dive are the three maneuvers which may be taken as imposing the severest stresses, and it is probable that in a loop skilfully executed the forces are inconsiderable. There remain the steep dive and the recovery from it. In the former the main forces acting on the wing are those of drag. The plane will, when it has attained its limiting speed, be at a very small angle of incidence, and between 50 and 75 per cent of the weight of the airplane will be supported by the drag forces on the plane. On recovery from a dive a totally different condition occurs. The machine is diving steeply, when the pilot pulls his elevator hard up and flattens out, describing a curve in space and imposing heavy centrifugal forces on the machine. In this case, before the machine has lost much of its diving speed it has been pulled up to a fairly large angle of incidence, bringing a very heavy lift load to bear on the wing truss, and the lift load on the wings is now much heavier than the drag load. No sand test can simulate both conditions, and hence a controversy is always possible as to the exact proportion of drag to lift which should be imposed in sand testing. As a compromise the tests of common practice are carried out under such conditions that the lift-drift ratio is as 4 to 1. This purely conventional loading at least simulates to some extent the conditions existing under a heavy dive, and at the same time we get a sufficiency of lift loading. Once adopted, and all machines being tested in the same way, we get at least comparative figures.

Fig. 1 illustrates how the lift and drift components are replaced by the simple force of gravity. Suppose that the wing is in flight at an angle of 2 deg. to the relative wind, and the lift-drift ratio under these conditions is 10. If under sand load the wing is placed upside down, with its leading edge up at an angle of 5.2 deg. with the horizontal, the components of the gravity force along and perpendicular to the chord will have the same relative values as the components of the lift and drift along and perpendicular to the chord.

Digitized by Google

Resolving forces along and perpendicular to the chord in full flight, we have, in a simple analysis,

$$D \cos i - L \sin i \text{ and } D \sin i + L \cos i$$

In sand load we have

$$W \sin \theta \text{ and } W \cos \theta,$$

and writing $\frac{D \cos i - L \sin i}{D \sin i + L \cos i} = \frac{L/10 \cos 2° - L \sin 2°}{L/10 \sin 2° + L \cos 2°} =$

$$\frac{0.9994/10 - 0.03490}{0.0394/10 + 0.9994} = 0.08925 \quad \text{while}$$

$$\frac{W \sin \theta}{W \cos \theta} = \tan \theta = \tan 5.2° = 0.08925$$

With these simple principles established, and a number of aerodynamic refinements introduced, the sand testing of a wing truss becomes a not too difficult engineering problem. In Fig. 2 is shown a typical set-up of a plane before a sand test.

Sand is usually applied in small bags of 5, 10 or 25 lb. During loading the wings are relieved by the placing of jacks under the strut points, the jacks being slowly relieved when the loads have been placed, and deflection measurements are taken. Careful provision is made for limiting the possibility of a general collapse when failure occurs, as this would prevent the learning of valuable lessons that the inspection of a partially collapsed structure renders possible.

Beyond the mere numerical result of such and such a factor of safety, i.e., the wing truss being able to support so many times the normal load in flight, the designer or aeronautical constructor can learn a great many things from such an experiment. For one thing, it is a final check on inspection, as unduly early failure of a spar or a strut may disclose the fact that wood of poor grain or bad seasoning has been employed. The early failure of a shackle may lead to the discovery that an entire series of production shackles is valueless. In production work it is highly advisable to sand test a plane taken at random from say 100 specimens, this being the severest possible check on the inspection system at a plant.

Sand Testing the Control Surfaces

In testing control surfaces such as stabilizer and elevator it is also possible to test the controls themselves, the joy stick, the connecting system of torque tubes, elevator arms, etc. It is a peculiar thing that a designer is less likely to be in error on the design of the structure of the

Digitized by Google

wings than on the structure of the tail surfaces. The methods of stress analysis for the wings seem to be fairly well defined. For the tail surfaces fewer aerodynamic data are available; the structure is as a rule less determinate and the members so small that there is a tendency for calculations to be neglected. Cases occur where a plane may be designed with particularly strong wings of heavy construction and yet the elevator mast

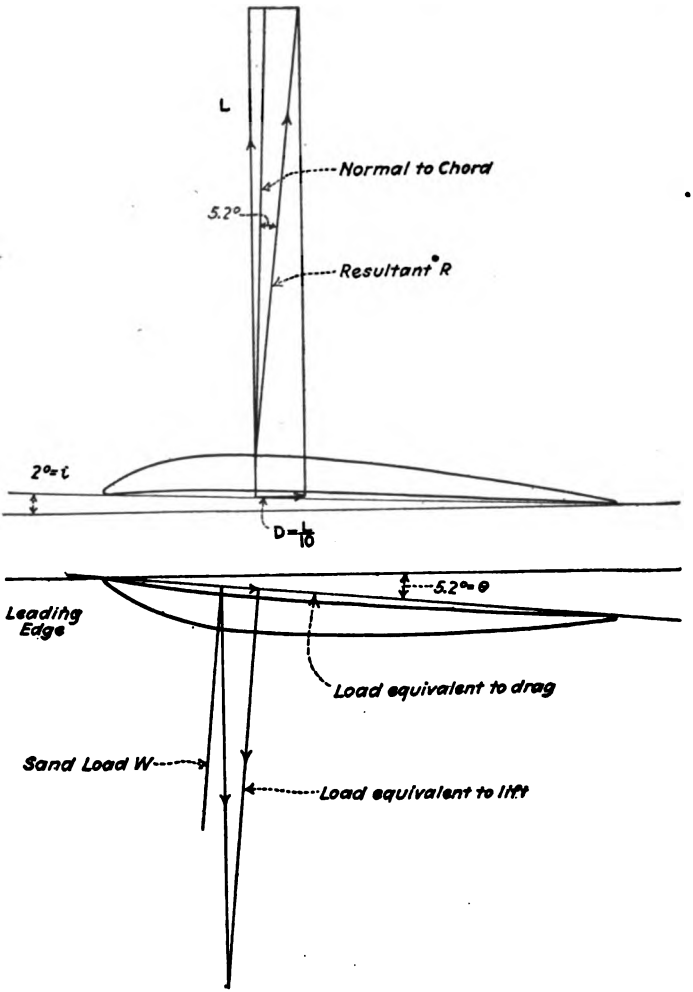


FIG. 1—DIAGRAM ILLUSTRATING HOW THE LIFT AND DRIFT COMPONENTS OF THE PATH OF AN AIRPLANE WING ARE REPLACED BY THE FORCE OF GRAVITY

Digitized by Google

be attached to the elevator in the flimsiest manner.

In Fig. 3 is shown a typical set-up of a test for the horizontal tail surface. Loads are applied and released in a fashion similar to that for the wings. For both the vertical and the horizontal tail surfaces a conventional loading is employed such that the mean loading per square foot of both the fixed and the movable surfaces is identical, but whereas for the fixed surfaces the loading is uniformly distributed, for the movable surfaces the loading is made to vary from zero at the trailing edge to a maximum at the leading edge. Such aerodynamic data as are available would seem to indicate that this method is rational. A study of numerous sand tests for the control surfaces indicates two or three specific points to be watched; viz, the attachment of elevator masts to the elevators, the necessity for having reinforcing wires from elevator masts to the trailing edge of the elevator in line with the control cable, etc.

The methods employed are too varied for discussion here. Tests reveal not so much weaknesses in the actual body structure as in the attachment of the lower wings to the fuselage, in the use of poor material in longerons, etc.

We are not concerned in a paper of this general character with the refinements of sand-testing methods. Sufficient has been said, however, to indicate that we have here a method which at least approximates conditions in the air. A plane which has successfully passed a sand test is not of necessity safe in the air, but it is quite certain that a machine which has not been successful on sand test is not safe in the air.

In the strength testing of airplane parts we are on ground which is much more familiar to the engineer. The small common types of testing machine are all that are required as a rule. Special machinery is in process of development for the proof testing of struts to the elastic limit with subsequent use on the plane. Rib-testing machines of various types are being developed. We may look confidently to the use of recording tension and stress meters in full flight for wires and cables. This branch of experimental aeronautical engineering while seemingly hackneyed and commonplace can be made to give the most useful lessons in the hands of skilful men who are not specialists in testing, but have an appreciation of aeronautical problems.

In the experimental study of performance, stability and controllability, there are two main avenues of ap-

Digitized by Google

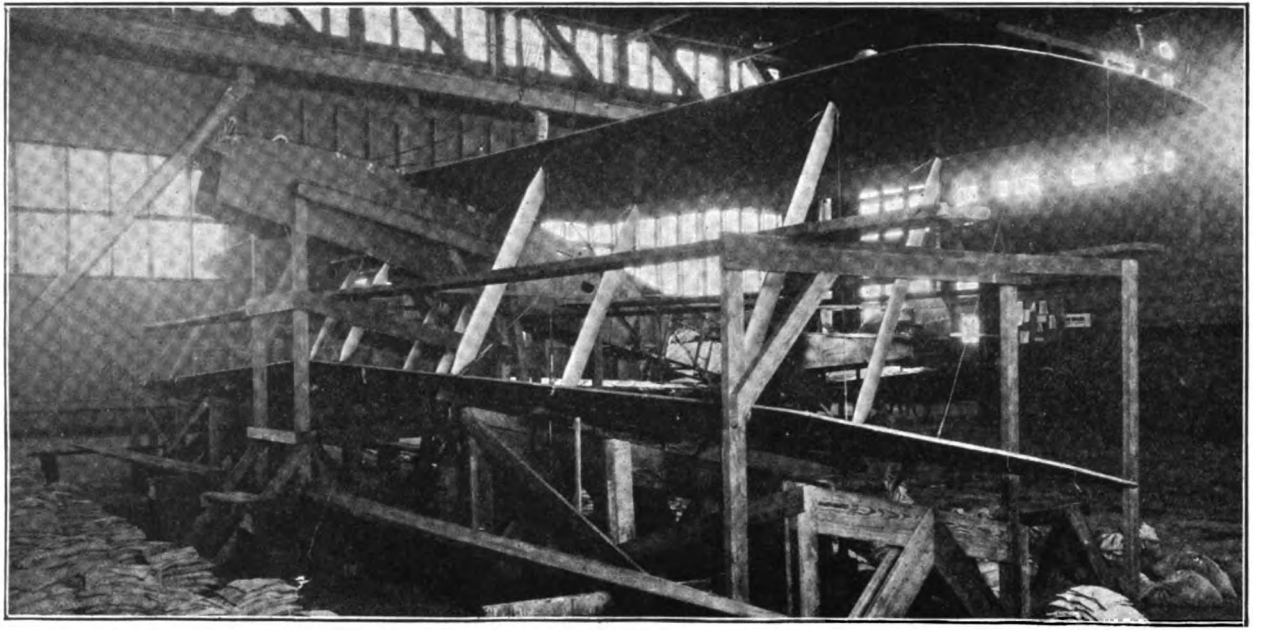


FIG. 2—A TYPICAL SET-UP OF AN AIRPLANE FOR A SAND TEST SHOWING THE ARRANGEMENT OF THE SCAFFOLDING AND SUPPORTS

Digitized by Google

proach; the wind tunnel and actual full-flight tests. Both have their definite utility and both can be misjudged and misused.

Performance Prediction by Wind Tunnel Tests

The technique of wind tunnel experimentation has been so often dealt with that it would be supererogatory to go into details on its principles and methods. Briefly speaking, we have in the wind tunnel a tube in which is placed a small model of the actual airplane, past which air is drawn at a well-regulated speed, while the forces on the model are measured on a suitable and carefully designed balance. Unfortunately, wind tunnel literature has been written very often by investigators of the utmost experimental skill, but of a restricted point of view. In such cases the tendency has been to view the wind tunnel as a final court of appeal.

It has been rightly pointed out that in the tunnel conditions can be made to suit the case, that no risk is present, that the expense and difficulty of small model experimentation are small, and that endless problems can be tackled. This is perfectly true. It is also true that great precision of measurement is possible in the tunnel, and that for the forces measured errors of not more than 1 per cent need be present. There are, however, certain very grave difficulties. The models can never be absolutely correct in view of the small scale. The scaling up of forces in accordance with the square of the linear dimensions and the square of the speed is not at all accurate. It can be demonstrated by the laws of dimensional theory that air forces on any body can be expressed by the equation

$$R = e\, v^2\, l^2\, f(v\, l)$$

where e is the density
l a linear dimension of the model
v the speed

Experimentation also indicates that the law of the square of the linear dimensions and the law of the square of the speed hold only provided the value of vl is a constant, i.e., the product of the linear dimensions and the speed. Even with the largest tunnel available and the highest speed compatible with a steady flow and no overheating in the tunnel, the full-size values of vl cannot be even approached. And it has been demonstrated both in the tunnel and by full-flight experimentation that with increased values of vl the lift coefficients increase and the drift coefficients diminish in value. It would seem at

Digitized by Google

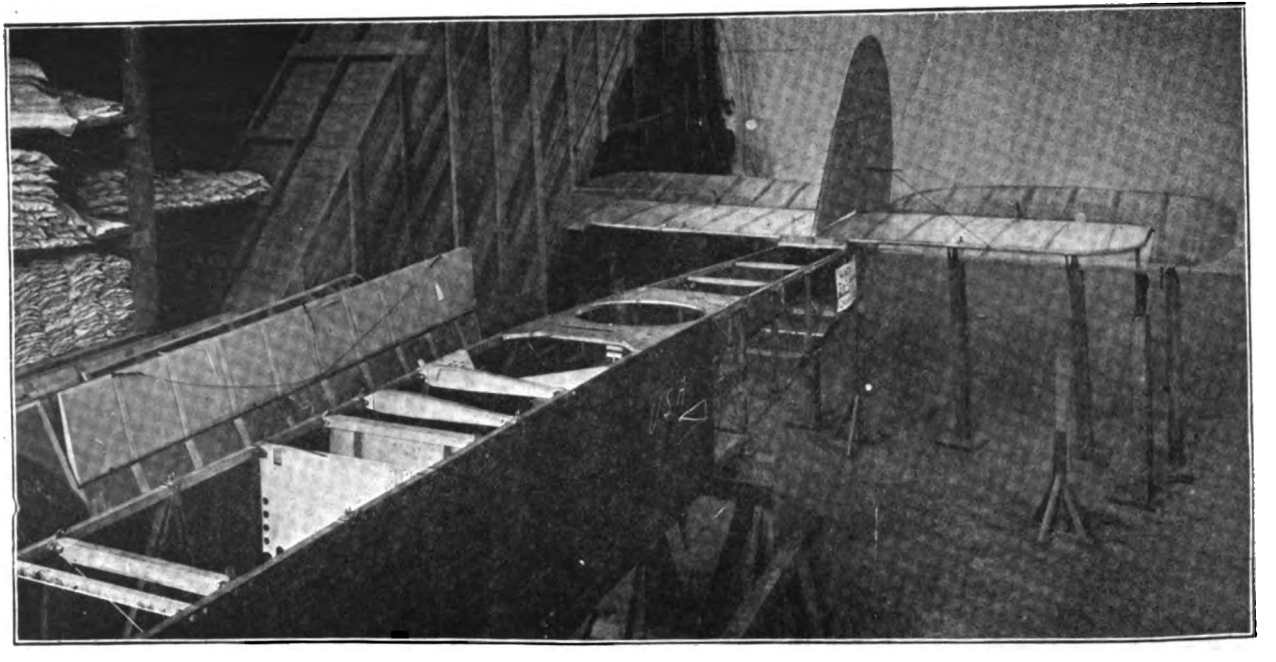


FIG. 3—A TYPICAL SET-UP OF A TEST FOR THE HORIZONTAL TAIL SURFACE

Digitized by Google

first sight as if the tunnel were useless for performance prediction. There is, however, an asymptotic effect to these variations, and by performing experiments in the wind tunnel at various values of *vl*, corrections can be obtained which will give fairly accurate transformation values from the model to the full-scale machine. By conducting full-scale experimentation in conjunction with wind tunnel work these correction values can be checked and with a little experience and some empiricism an almost exact prediction of performance can be obtained.

The practical man is right in criticizing the wind tunnel expert who places implicit faith in the prediction values given by the tunnel, but if the tunnel is rightly used and corrections based on experience skilfully applied, if engineering instinct is brought to bear on the subject, the tunnel can be used for prediction of performance. The value of this in experimental design need hardly be emphasized.

There is another aspect of the prediction of performance where the tunnel can give exact answers, namely, in the comparative study of machines. Even more important than to know what performance a machine will give, is to know whether one machine will be better than another. If accurate models of two machines are constructed, if they are tested with the same scale and under the same wind velocity conditions, the better machine can almost infallibly be selected.

Almost of the same order of importance in experimental design as the prediction of performance is the question of stability. Stability experimentation in the air is particularly unsatisfactory and even dangerous. A bad error in the stability of a machine may result in an accident on the first flight. The question arises how far the wind tunnel stability tests can be trusted. While the scale effect $f\ (vl)$ causes variation in lift and drift coefficients it has but a slight influence on the movement of the center of pressure. If the stability on a glide is considered, therefore, the wind tunnel center of pressure or force vector diagram can be implicitly trusted. But when the engine is running the slipstream of the propeller has a disturbing effect on the tail of the machine, and exactly what this disturbing effect is remains a matter for investigation. Here again the wind tunnel results must be skilfully used.

If stability tests in the air are coordinated with wind tunnel tests, if empirical corrections are made for a num-

Digitized by Google

ber of machines, the engineer will be able to pass on the longitudinal stability with sufficient accuracy. Particularly when trying out a new machine, with a new wing curve, or a tapered wing, or a swept-back wing, a wind tunnel test is absolutely essential to give some idea of the variation from the normal. On the whole perfectly satisfactory results can be obtained if engineering empiricism is combined with scientific method. Either an implicit trust in the scientific method or a brutal disregard for it will sooner or later lead to dangerous results. For lateral stability, where slipstream effects of the propeller are negligible, the tunnel provides an almost exact criterion.

In controllability little has been done in the tunnel hitherto. Constructors have preferred to build machines with fixed and movable surfaces proportioned in accordance with the average values of previous successful types. The method is safe as long as we are dealing with average types. But if new types are evolved, exceedingly large or very small machines, then something more exact will be required. It will be necessary to make a study of the moments of inertia about various axes, and then for various settings of the tail surfaces, to determine the controlling moments which can be imposed, and to fix certain ratios between the two. In work of this character the tunnel will be indispensable.

Full-Scale Methods of Performance Testing

For the testing of performance a complete and satisfactory technique has now been developed. With the aid of a few simple instruments such as a barograph, a recording thermometer, a recording speed-indicator and a tachometer, complete engineering data can be obtained on maximum speeds, rates of climb, the revolutions of the engine, ceiling, speeds at various altitudes, etc. The sole requirement which constitutes a real difficulty is the calibration of the air speed indicator. No matter how carefully constructed or calibrated in the laboratory, the air speed indicator must be calibrated over a measured 2-mile course, and since this has to be done at an altitude of not more than 1000 ft., the field has to be very large or the surrounding country very clear of obstructions.

It may be stated that the testing for performance has now reached a point of sufficient accuracy. There may be further refinements, but from the practical engineer's standpoint the problem of full-flight testing is on a per-

Digitized by Google

fectly satisfactory basis. The real snags now are not in the instruments or in the methods, but in the careful preparation of the plane and engine for test, and in the work of the pilot. Two pilots climbing the same machine may show a difference in altitude of over 1000 ft. in the first 10-min. climb, because one of them has not selected that speed on the climb which gives the best results. A faulty carbureter adjustment may spoil the record of a perfectly good plane; a variation in incidence of the main planes may spoil the climb.

In the tests for stability, reliance has hitherto been placed almost entirely on the judgment of the pilot, with the result that one pilot may report a ship tail-heavy, and another nose-heavy. The great problem here is to eliminate the personal equation. This can be done by very simple methods, such as placing spring balances on the joy stick to show the exact effort exercised by the pilot under varying conditions of flight, or by using gadgets to indicate the position of the elevator for various conditions of flight. If such methods come into general use not only will the personal equation be largely eliminated, but a great deal of exact data on stability collected which will facilitate further designs.

The difficulties in devising the scientific testing of lateral stability are exceedingly great. For the time being we have to place entire reliance on the pilot's report of how the airplane executes certain maneuvers, such as steep banks, side slips, etc. To a very great extent this is true for controllability also, and no criterion beyond the pilot's opinion seems possible at the moment.

The scope of general full-flight testing beyond performance and stability and controllability testing is almost endless. The installation of a thrustmeter will give us the most valuable information on the propeller. The final answer as to whether radiators on the nose of the fuselage, a radiator in the wings or free radiators on the sides or underneath the fuselage are to be used can be supplied only by a systematic investigation on the same machine. The scope of such work is endless. Not only will it have a scientific value in the accumulation of knowledge, but it will repay the practical constructor by the improvement of his machine.

Digitized by Google

MOTOR-TRUCK MEETING PAPERS

PNEUMATIC TIRES ON TRUCKS

By B B Bachman[1]

THIS paper records the results obtained from operating medium-weight trucks on pneumatic tires, and points out the advantages and disadvantages experienced. An analysis is made of the claims advanced in support of the use of pneumatic tires. Certain items are specified which in the author's opinion require further development before a satisfactory solution can be reached.

The use of pneumatic tires on trucks has been a subject of considerable interest for some years. At the annual meeting of the Society in 1913 I presented a paper on this subject and covered the matter in a more or less general fashion. Since that time considerable progress has been made in truck construction and a very great advance in pneumatic tires due to the appearance of the cord tire, whereas at the earlier date the fabric tire was used almost exclusively. The cord tire, permitting the construction of very large sizes with corresponding carrying capacities, has made it possible to use the pneumatic tire on trucks up to 3-tons capacity and in some cases even beyond.

The most pertinent questions that arise in connection with determining the feasibility of the use of pneumatic tires are probably these:

(1) On what sizes of truck can they be used?
(2) In what class of service?
(3) On what kinds of road?
(4) What advantages are obtained?
(5) What disadvantages become evident?
(6) Will it be necessary to radically modify truck construction to use pneumatic tires most economically?

An analysis of data contained in *Automotive Industries*, Jan. 16, 1919, shows that on trucks ranging from 1000-

[1]Engineer, Autocar Co., Ardmore, Pa.

Digitized by Google

lb. to 5-tons capacity the maker's equipment for tires is as given in the accompanying table:

Capacity, tons	Number of models	Solid only	Pneumatic only	Optional
½	14	0	13	1
¾	18	3	14	1
1	64	41	8	15
1¼ to 1½	71	59	1	11
2 to 2½	128	118	2	8
3 to 3½	81	80	0	1
5	62	62	0	0

It must, of course, be recognized that this does not give an indication of the cars which have had their equipment changed by the owner after purchase, and probably does not give an indication of the cases were pneumatic equipment has been furnished at the customer's request. Conversely, if a sufficiently large demand had arisen, the manufacturer would undoubtedly have recognized the fact by listing optional equipment.

The Field of the Pneumatic Tire

Viewing the figures with these facts in mind, it would seem to be safe to say that for vehicles up to 1500-lb. capacity pneumatic tires only are proper. From 2000 to 3000 lb. inclusive there is a strongly marked tendency toward pneumatics, and on 2 to 2½-ton trucks they are just making an appearance, while on the larger sizes there is practically no evidence apparent from this source. We have all seen large trucks of 3, 4 and possibly 5-tons capacity with pneumatic equipment, and the fact that makers are not listing them would indicate that the proposition is still in the experimental stage.

On the smaller-sized vehicles in the delivery field, there is hardly room for discussion as to the desirability and even necessity of pneumatic tires, as the speeds are high and construction follows closely on passenger vehicle lines. If these cars were made rugged enough to operate on solid tires, it would only require the increasing of the capacity of the spring equipment to make them suitable for possibly double their present ratings.

In the 2000 to 3000-lb. class, it is my opinion that except for limiting factors which will be covered later, all vehicles would operate more economically and satisfactorily on pneumatic equipment. The reason for this opinion

Digitized by Google

is that on this size of vehicle the tire equipment does not become so expensive in initial installation as in larger sizes, and it is easier to realize on the advantages of increased speed, etc., without attendant difficulties.

Vehicles in the 2 to 2½-ton class are, I believe, likely to follow the last class, but to do so it is my belief that a different theory of design will have to be followed. Generally speaking, the cars in this class are too heavy in proportion to their capacity. This means that to carry the unnecessary burden caused by solid tire construction, excessively large and consequently expensive tire equipments must be used. It is only natural therefore that when the customer is faced with an initial equipment expense 100 to 200 per cent greater than for solid tires there is considerable hesitation about going into the proposition.

For the 3 to 3½ and 5-ton classes the foregoing remarks apply with possibly greater force. Also the utility of this equipment will probably depend on the future development of long distance truck haulage.

During the conditions existing for the last eighteen months in the congestion of railroads and terminals, etc., the use of large trucks for long distance hauling has come into considerable prominence. Under these extraordinary conditions many considerations which would normally have to be reckoned with were left out due to the absolute necessity of utilizing every available means of transportation.

The increase in operating speed demanded by these conditions to obtain favorable results on these larger sizes has undoubtedly been followed by high mechanical depreciation on the part of the car and rapid disintegration of road surfaces. It is only natural, therefore, that the pneumatic tire was resorted to as a means of alleviating both these conditions, and undoubtedly results obtained were in many cases successful.

The question still remains to be answered, however, as to what the future will show as to the radius in which truck transportation can compete with various other forms and what size of unit will be most satisfactory. These questions hardly have a proper place in this discussion and are mentioned only to indicate that they exist and will have a bearing on our present subject.

To sum up then, it seems that for vehicles up to 1500-lb. capacity inclusive pneumatic tires should be used except under very rare conditions. Vehicles of 2000 to

Digitized by Google

3000-lb. capacity should be rapidly changed to pneumatic equipment in the large majority of cases, due to the appearance of the cord tire. A considerable percentage of 2 to 2½-ton vehicles will probably be placed on pneumatic equipment when the subject has been more clearly demonstrated to the public and after design changes which may be found necessary have been made. On the larger vehicles, it is my personal belief that a great deal of work must be done on a complex subject involving transportation problems, road construction, vehicle construction as to chassis, powerplants and wheels, and also with the tires themselves and rim equipment, before any definite prediction can be made.

The type of service in which pneumatic equipment should be used will cover first of all light delivery service of all kinds, for it is in this field that the small car up to 2000-lb. capacity is used.

In the sizes embracing the 3000-lb. and 2 and 2½-ton classes, the conditions where materials are fragile or where delivery conditions require long runs with frequent stops are the places where the best showing has been made. Typical instances of this kind are delivery of foodstuffs in suburban territories and the recent development of the parcel post system in hauling farm products into the market.

With the larger size trucks the only place, it would seem, for the use of pneumatic tires is in that class of service covering long hauls, where speed requirements are high. One reason for making this statement is that with these larger size vehicles the loss in time due to improper handling facilities at terminals is so great that where hauls are of normal length more can be gained in speeding up the handling than by increasing the car speed.

A limiting factor to all of the preceding statements is to be found in the character of roads on which pneumatic equipment is operated. When vehicles are operated in part or entirely over roads which are littered with scrap metals, glass, etc., as is the case in certain kinds of work, the pneumatic tire will not have a fair opportunity to demonstrate in a satisfactory manner.

The modern cord tire is excellent for operation on almost every kind of road. The structural strength of these tires renders them less susceptible to injury from stone bruises, etc., when operated on rough roads if the proper inflation pressures are used than with the fabric type. The types of treads which have been developed

Digitized by Google

are of great assistance in snow, mud and on wet surfaces. In consequence, with these advantages it is safe to say that the pneumatic tire will compare favorably with the solid under almost every condition of road.

Advantages of Pneumatic Tires

The advantages claimed for the pneumatic tire are numerous. Some of these claims are so obviously correct as to need practically no discussion; others are open to considerable question. Also, as with every matter of this sort, the answer is not to be obtained from any one factor in the problem, but after the bearing which each factor has upon all the others has been given consideration.

The claims of advantage which are made may be listed as follows:

(1) Reduction in mechanical repairs
(2) Increase in permissible speed
(3) Decrease in gasoline consumption
(4) Decrease in oil consumption
(5) Less fatigue for men
(6) Lessened depreciation of roads
(7) Greater tractive ability

The reduction of mechanical troubles can be accepted as a fact almost without comment. One point to be considered, however, is that while the net trouble is reduced, it is apt to change in character. With solid tire equipment, due to the shocks on the portions of the chassis which are not spring borne, the greater amount of difficulty is caused by the wear and looseness developed by this action. The small amount of resiliency in the wheels causes sharp blows to rack and twist the chassis structure, whereas the pneumatic tire absorbs a larger proportion of these shocks, and thus reinforces the spring action in relieving the chassis. There is, however, a reverse side to this, caused by the greater speeds which in spite of the generally larger sized wheels result in higher engine speeds. This sets up mechanical vibrations, which in conjunction with other troubles engendered by high engine speeds raises the proportion of trouble in this part of the mechanism. However, as stated before, the total amount of trouble is decreased, and this becomes more apparent when placed in proportion with the car mileage.

Digitized by Google

This is illustrated to some extent by the experience on a group of 1½ to 2-ton cars numbering about sixty, which are being operated on long distance transfer work. The mileage is running between 50,000 and 60,000 miles per year. The distances covered by each car range from 130 to 205 miles per day, this high daily mileage being made possible by properly regulating shifts for the men. Unfortunately there is no parallel service on solid tires to compare with, but it is the opinion of competent observers that the repair cost for these cars is 50 per cent of the probable cost on solid tires, and it is extremely doubtful if the work could be performed at all with solid tires on anywhere near the present schedule.

Reports from these cars indicate an extremely small amount of mechanical trouble in the axles and chassis. It is estimated that 75 per cent of the repair work is on the powerplant, and a considerable, if not the greater, proportion of this is due to the fact that the increase in speeds has not been accompanied by more care in following up lubrication, etc.

To anyone who has attempted to drive a vehicle on solid tires on any but roads in absolutely perfect condition, and particularly if the car was not loaded to a point where the springs were operating to their full extent, the limitations on speed are painfully apparent. The writer has driven a 3-ton truck on solid tires 165 miles at an average of 17 miles per hr., and as a result is prepared to discourage anyone from doing likewise with the thought in mind that the experience is pleasant. On pneumatic tires this would not be at all difficult. This ability to increase the speed of the vehicle materially increases the distances which can be covered, and is one of the most important advantages to be gained. As pointed out before, however, the gain will be limited if the proportion of idle time at terminals and delivery points is high, and this is one of the, at present, undetermined factors in predicting the degree of success which will follow the use of pneumatic tires on larger sizes of vehicles.

The question of relative gasoline consumption is not so easy to dispose of. Many claims are made as to increase in economy effected by use of pneumatic tires. Unfortunately, the supporting evidence in many cases is, to say the least, incomplete. Comparisons are made in some instances between vehicles of different makes, in others between vehicles of the same make but operating under dissimilar conditions, and so on. Any one who has

Digitized by Google

attempted to collect accurate data on this subject can appreciate the large number of variables which can influence the results and will understand how hard it is to assign a value to each of these variables.

On the group of vehicles mentioned above the average of gas consumption for all the cars is very close to 35 gross ton-miles per gal. On this type of car with solid tires, 30 to 32 gross ton-miles per gal. is considered average performance. These figures are not directly comparable, however, for the reasons enumerated.

I have made some tests using the same car and nearly the same loads over a route of 272 miles, with average road conditions as to surface and gradients. The solid tires were 34 in. in diameter, and the axle gear reduction was such as to give 69.3 r.p.m. of the engine per mile per hr. of the car. The pneumatic tires were 38 in. in diameter and gave 62.7 r.p.m. per mile per hr. Three series of tests were made, one with solid tires, one with the pneumatics on the same axle reduction, and the third with the axle reduction altered to compensate for the increased tire size.

Runs were made with different loads; in the case of the solid tire one run was made with a considerable overload, which was not duplicated on the pneumatic tires. The results obtained are tabulated on page 467.

These tests were made as carefully as possible and are, to say the least, disconcerting in the results shown. It is possible, and in fact very probable, that these results are due to the form of the tires, which were not of the conventional cross-section and were designed to operate at considerably lower inflation pressures than normal.

General observations lead me to believe that the performance with regard to gasoline consumption will vary according to the road conditions. On very good roads there will be little or no difference, while on bumpy roads the pneumatic tire will show up the better.

With regard to the claim for decreased oil consumption I can see no good reason for any change in this particular. If there is any difference I should think it would be to show a higher consumption for pneumatic tires, because on the whole the engine speeds will be higher, and as the wheel diameters are greater the engine will be required to develop high average pressures, that is, it will be operating at a greater throttle opening more of the time.

Digitized by Google

The decrease in strain and the resultant lessened fatigue of the driver is a very important advantage. It is difficult to assign a definite relative value to this feature, but it needs little discussion to realize that the efficiency of the machine is dependent on the efficiency of the operator, and anything which favorably affects the latter will be reflected in improvement in the former.

The question of the effect of heavy truck traffic on roads is one which is occupying a prominent place in the thoughts of those charged with their construction and maintenance. The claim is made that the pneumatic tire lessens the strain on roads caused by the larger sizes of trucks. On what this claim is based it is hard to say. There has not, up to the present time, been sufficient experience with pneumatic equipment on trucks of 3-tons capacity and over to give accurate data on which to base an opinion.

Observations made on the highways traversed by heavy truck traffic during the last eighteen months indicate that a large amount of the trouble was due to the failure not of the surface but of the foundations, and while it may be argued that this was in part due to shocks and vibrations, it is my opinion that the real reason was simply overload. Given a good road as to foundation and surface, and trucks operated at reasonable speeds with respect to their size, and I do not believe that any great difference in road depreciation will be found.

One very great advantage of the pneumatic tire is the greater adhesion possible, particularly with the types of so-called non-skid treads which have been developed. This feature has shown itself to be of great value, especially during the severe weather of last winter, when pneumatic tired trucks repeatedly demonstrated their ability to keep going, while solid tire equipment was in continual difficulty.

Objections to Pneumatic Tires

The objections to pneumatic tires are not so numerous but need careful consideration lest we be carried away with the idea that their use offers a solution for all troubles with no problems of their own needing attention. These objections are in my opinion:

(1) High initial cost compared with solid tires
(2) The need of carrying emergency equipment

Digitized by Google

(3) The difficulty attendant on making road changes due to weight and high inflation pressures required

(4) Reduction of the high gearability and limitation of the total ability due to larger diameter of wheels

(5) Limitations imposed on the size of brakes due to the small size of wheels

I have taken the data published in the issue of *Automotive Industries* previously referred to and determined the average solid tire equipment of trucks from 1 to 5-tons capacity. By taking the tire capacities corresponding to these sizes, it is possible to select approximate pneumatic equipment and thus get an idea of the comparative initial cost of the equipment. The results obtained are given on page 468 in tabular form.

On the 1-ton size only one extra tire is figured in, as the front and rear ones are the same; for the other sizes two extra tires are figured. It is possible by increasing the size of the front tires on the 1¼ to 1½-ton class to

Test number	Weight empty, lb.	Load, lb.	Total weight, lb.	Ton-miles per gal.	Total time in high gear, per cent
1[a]	4,500	525	5,025	30.33	89.1
2[a]	4,500	2,350	6,850	32.45	77.7
3[a]	4,500	4,175	8,675	36.35	62.7
4[a]	4,500	5,900	10,400	42.00	57.1
5[b]	4,500	680	5,180	28.20	81.3
6[b]	4,500	2,000	6,500	32.10	74.6
7[b]	4,500	3,580	8,080	31.96	62.1
8[c]	4,500	550	5,050	24.40	88.2
9[c]	4,500	3,480	7,980	27.40	68.0

[a]Solid tires.
[b]Pneumatic tires and the same axle reduction.
[c]Pneumatic tires and a changed axle reduction to compensate for the greater wheel size.

Digitized by Google

Truck capacity, tons	Solid tires front, in.	Solid tires rear, in.	Pneumatic tires front, in.	Pneumatic tires rear, in.	Increased cost pneumatic tires over solid, per cent	Increased cost pneumatic over solid including extra tires, per cent
1	34 × 3½	34 × 4	35 × 5	35 × 5	80	125
1¼ to 1½	34 × 3½	34 × 5	35 × 5	36 × 6	93	184
1¼ to 1½	36 × 3½	36 × 5	35 × 5	36 × 6	77	165
2 to 2½	36 × 4	36 × 7	36 × 6	40 × 8	110	216
3 to 3½	36 × 5	36 × 5 dual	36 × 6	44 × 10	87	180
5	36 × 6	36 × 6 dual	38 × 7	44 × 10	60	140

have all tires alike, and this would in all probability be desirable.

Based on these figures, it will be seen that a material increase in tire mileage must be obtained to bring the cost per mile down to within a reasonable comparison with solid tires. Fortunately, this seems perfectly possible, at least up to 2-tons capacity. On the group of cars which has been used before in this article for illustration, the grand average of reported mileage to date is 14,000 miles. One make of tire has averaged 19,000 miles, and of all the tires none has given less than 6000 or 7000 miles.

This objection then resolves itself into a proposition of increasing the difficulty of getting the truck owner interested on account of the greater investment. To offset this, experience on cars up to 2-tons capacity at least, indicates that the longer tire life obtained, together with the compensating factors outlined above under the head of advantages, will pay a reasonable return on this increased investment.

The need for emergency equipment is a distinct handicap, not only from the standpoint of initial expense, but because of the difficulty in providing a

Digitized by Google

suitable place for carrying these large sized tires so as to be accessible and yet not encroach seriously on the cargo space or interfere with the operator when getting into the truck.

The question of road changes for punctures, etc., is a very serious item. While these troubles are guarded against in the tire construction and are reduced to a minimum, they cannot be eliminated and the penalty incurred by running on a flat tire is too great to be considered. The two bad features in this proposition are the weight of these tires and rims and the high inflation pressures required.

The weights are roughly as follows for an inflated tire and demountable rim: 38 by 7-in., 152 lb.; 40 by 8-in., 218 lb.; 44 by 10-in., 400 lb. These figures represent weights that require much handling.

Inflation pressures recommended are: 5-in section, 80 lb.; 6-in., 90 lb.; 7-in., 100 lb.; 8-in., 110 lb.; 9-in., 120 lb.; 10-in., 130 lb., and 12-in. 140 lb. It is impracticable to consider hand pumping for any but the 5-in. size, and a mechanical pump installed correctly adds another considerable item of expense which must be taken into consideration.

By referring to the table it will be seen that the driving-wheel diameters are increased as follows:

Capacity, tons	Old diameter, in.	New diameter, in.	Increase in diameter, per cent.
1	34	35	3
1¼ to 1½	34	36	6
2 to 2½	36	40	11
3 to 3½	36	44	22½
5	36	44	22½

On the smaller sizes the change is not so great and will probably work no material hardship except in cases where the brake equipment is on the transmission. With the larger sizes the difference is so great as to make it extremely doubtful whether there is sufficient flexibility in any well-designed truck to permit successful application.

The larger sections used in these tires together with the space taken up by the demountable rim leave a very small wheel diameter remaining, and this imposes severe limitations on the size of brake equipment and decreases the ability of the brakes at the same time. This is a

Digitized by Google

very important matter, on account of the fact that the greater speeds put considerably heavier duty on the braking systems.

The heavy-duty pneumatic tire, particularly in the larger sizes, has come into prominence in the last few years when engineers were so completely occupied as to leave little time for the thorough investigation of the subject to determine what effect their use would have on future design. That there will be need of a considerable change in design with respect to some particulars seems very evident.

The increase in speed carries with it a demand for more efficient brake equipment. Whether the present style of direct-acting brake can be developed further to do the work on the larger trucks is a question which will have to be considered. Inasmuch as air pressure will be needed to inflate the tires, calling for an efficient air compressor, it may be found feasible to add the other elements necessary to provide for the use of airbrakes.

Trucks as built at present have been developed for solid tires. The factors of safety in the load-carrying elements have been made sufficiently great to provide for the shock incident to their use. The gear ratios in axles and transmissions have been designed on the basis of the wheel diameters in common use. The thrust capacities of the bearings and the torsional strengths of axle, transmission and propeller-shafts have also been calculated on these wheel diameters. Increasing the wheel diameters has created an entirely new set of conditions which must be investigated before the answer can be safely stated.

This does not mean that pneumatic tires cannot be used successfully with trucks as they are built today. They not only can, but are being so operated. It does mean, however, that particularly on the larger sizes, the truck engineer must recognize the new conditions which confront him and must prepare himself to meet them by making careful investigation on the subject and learning the relative importance of the items herein suggested and possibly others which have been neglected.

The statements made herein are exceedingly general in character. Experience on this proposition is apt to be so varied that exceptions to my deductions are likely to be numerous. If this is so and discussion is created which will throw more light on the subject, the purposes of the paper will have been fully served.

Digitized by Google

THE DISCUSSION

J. E. HALE:—Comparisons of cost between solid and pneumatic tires at this time are not really useful. When the tire makers have had a chance to get into volume production on pneumatic truck tires, and down to bed rock in the matter of improving the quality on the one hand and eliminating expensive constructions on the other, we shall be able to tabulate costs. There are one or two places where I think the sizes should be chosen differently. For instance, on the rear of the 1-ton truck there should be a 6-in. tire, and on the rear of a 1½-ton truck a 7-in. tire. The rear tire of a 5-ton truck should be 12-in.

Pneumatic tire equipment for passenger buses has remarkable possibilities. It has already been used to a considerable extent and promises to open up the passenger bus field in the most remarkable and profitable way. A volume might be written on the enormous possibilities accruing from an increase in permissible speed. We who have had experience in operating trucks of all sizes up to 5 tons on pneumatics have come to realize that motor trucks, provided they have the power, can be operated at any speed within the bounds of safety. Another item is the control which the driver has over the truck. The freedom from skidding on bad streets is very noticeable.

Another advantage not at once apparent which should be regarded as the most important of all, is the increased radius of operation and all-round extension of service which is permissible on pneumatic-tired trucks. This is most important because of the fact that a truck with pneumatic tires can cover so much more ground particularly in inter-city haulage where, up to the present time, it has been inadvisable to use solid-tired trucks.

The five objections to pneumatic truck tires which Mr. Bachman mentions will either disappear entirely or be greatly diminished in importance by improvements in the tires and the redesign of the trucks themselves.

S. P. THACHER:—The advantages of pneumatic tires for trucks, which Mr. Bachman lists as claims and of which he says some are open to question, have been so thoroughly substantiated by data which I have collected in the past 8 months, that there should no longer be any doubt in the minds of truck engineers that their brothers in the tire industry will make possible, as they have for the passenger car, any and all truck performance characteristics which fall within the sphere of tire problems.

Digitized by Google

MOTOR TRUCK CHASSIS DESIGN

By Cornelius T Myers[1]

BECAUSE of the successful foreign service already accomplished by motor trucks, the author believes that the American truck builders will now secure a large amount of foreign business. Although the general types of motor truck chassis are correct, more attention must be paid to details of design to satisfy foreign customers, since the trucks go far beyond the reach of the factory and service stations. Good design requires reliability, accessibility, simplicity, light weight and economy of operation. Under these several heads the present output of truck builders is set forth, explained and criticised.

Accessibility is no mean qualification, simplicity is absolutely essential for quick repair. The fewer the chassis parts the more accessible they are and the greater the wrench clearance available. The more weight that is added to a chassis the less its pay-load capacity becomes. Every pound judiciously removed means less power required for driving and less wear-and-tear on tires. Weight reduction affects speed. Economy in operation covers far more than fuel, tires and repairs. The nervous energy of the driver is part of the problem; his comfort has much to do with the service rendered. In addition to the minimum of details requiring attention and care, good springs, easy seats, well arranged controls and protection from weather should be provided.

The need of training drivers for their work is urged. Service should mean not something rendered in a garage to keep trucks on the road, but something embodied in the product, which must be designed and redesigned, studied and perfected to every reasonable extent before being sent out under the builder's trademark.

A period of great stress in the motor truck industry has just passed. A vast demand for its product arose. The trucks themselves have magnificently filled a colossal and distressing need, and the industry has met the demand with a 100 per cent response. The performance of our motor trucks has been one of great merit. Tried under the hard service of war-time necessity, they have reflected credit upon our

[1]Consulting engineer, Avenel, N. J.

Digitized by Google

industry and have established a world-wide reputation for it. True, there have been faults in design and weaknesses of construction that were brought out from time to time. Most of these developed from a service more strenuous than that for which the trucks were originally designed, but the proper recognition of these deficiencies will serve as a guide for the present and future.

With the United States at last taking part in world affairs, and considering the foreign service of our motor trucks, it is quite reasonable that the energetic American truck manufacturer should look abroad for considerable foreign business. He will get it, beyond a doubt. I have recently talked with a number of men well acquainted with foreign demand and competition in motor trucks. They have all said that there was an undoubted opportunity for us to get well established abroad, but almost invariably have questioned one or more details in connection with the particular truck or trucks under discussion. Some of these men were the heads of export houses, others in export organizations of standing. In their case the cost of an initial sale in distant countries often exceeds not only the nominal profit but the invoice itself, and the profit comes from the repeat orders of satisfied customers. These exporters were chiefly concerned with the attention paid to details of design, since the trucks go far beyond the reach of factory or service station. This brings us back to the very comforting reflection that our general types of chassis are correct.

What Good Design Requires

In the progress of development we have seen practically all types give way to the truck with a four-cylinder four-cycle engine mounted near the front of the frame and just back of a built-up radiator, the driver's seat behind the engine, a selective controlled three or four-speed gearbox, a propeller-shaft with two or more universal joints and a rear axle with an enclosed drive. This type became popular because of the comparative accessibility of all its parts. While reliability is the first requisite of a motor truck, accessibility is a close second; so when the component parts of the chassis were in a state of development and needed considerable attention, the type of chassis design that afforded ready access to the various units or parts thereof was bound to prevail. Now that unit reliability has been better established we are likely to see more modifications of the prevailing type.

Digitized by Google

The second requisite of a motor truck, the accessibility of its parts, is no mean qualification. Many an offending part has been condoned because of its ease of adjustment or renewal, and many a truck-hour has been saved by the owner on this account. Whether detail parts are nearly enough perfect for us to compromise their accessibility is a matter for nice judgment. Even though average performance is good, the chance of accident must be carefully considered. Major units should be so assembled that each can be taken down for repairs with the least disturbance of other parts or units. Fastenings should be not too complicated or too close fitting. Hours of time are lost in the service station, garage or repair shop due to small shortcomings under this head.

As the third requisite I shall put down simplicity. The fewer parts there are on a motor truck chassis, as long as it still functions properly, the better it is for the owner, the driver and the manufacturer. There are so few parts on a chassis that do not demand attention at one time or another that any absolutely unessential thing is a detriment, however pleasing it may look on the salesroom floor.

A well-known operator of many trucks in New York told me that as often as a new chassis was delivered to him he personally made an inspection to see what he could remove from it. He invariably found a large collection of troublesome stuff which he sold to other users of the same model who felt that these should continuously be a part of their truck's equipment. An attachment added to an unsatisfactory device to make it function better is a poor substitute for a more satisfactory device. The fewer parts there are on a chassis the more accessible are all of the parts and the more wrench clearance is available. This matter of wrench clearance is much appreciated by the repair-man and helps to sell trucks.

Fourth in order of importance I should put weight. The more weight we add to a given chassis the less becomes its pay load capacity. Of course it is quite possible to lighten parts to the extent that they are too weak to function properly; but on the other hand careful study and analysis will reveal ways of reducing the weight of a chassis without affecting its serviceability. Every pound removed from the chassis adds a pound to the load carrying ability of the truck, or calls for less power in driving and less wear and tear on the tires. Weight reduction also affects speed, as is mentioned later.

Digitized by Google

Fifth on my list is operating economy—pertaining to fuel, tires, repairs and the nervous energy of the driver. We have a big problem before us as regards fuel consumption, and from the opinions of well-known authorities the situation bids fair to become worse in the immediate future. We are not doing today nearly the best we can do with the fuels we have.

Fig. 1 illustrates the estimated petroleum reserve in the United States and the increasing rate at which it is being consumed. Other sources are problematical and not immediately available.

Fig. 2 shows the great and rapidly increasing demand

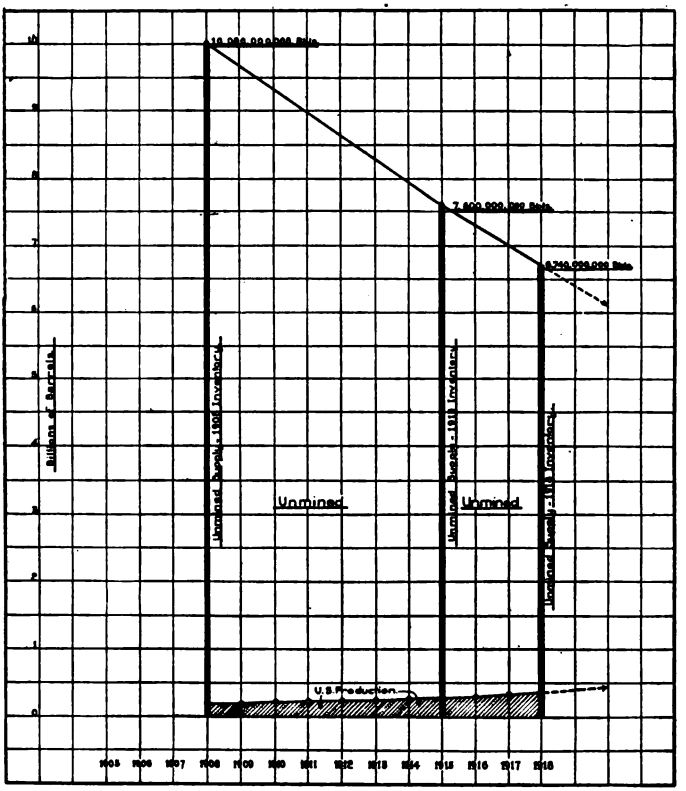


FIG. 1—THE DOMESTIC CRUDE PETROLEUM SITUATION FROM DATA COMPILED BY THE U. S. GEOLOGICAL SURVEY

(From a paper entitled "An Interpretation of the Engine Fuel Situation," presented by Joseph E. Pogue at the 1919 Annual Meeting of the Society)

Digitized by Google

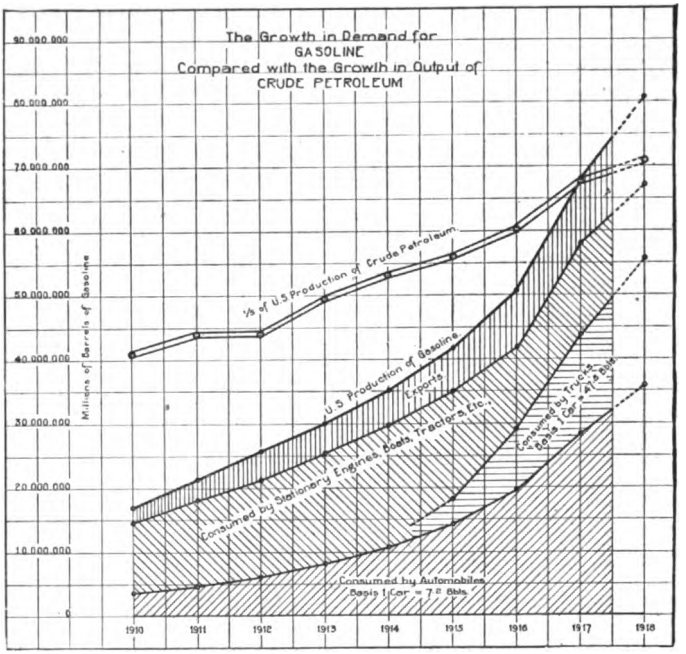


FIG. 2—CHART OF THE GASOLINE SITUATION FROM DATA SUPPLIED BY THE U. S. GEOLOGICAL SURVEY, U. S. FUEL ADMINISTRATION, U. S. BUREAU OF MINES, NATIONAL AUTOMOBILE CHAMBER OF COMMERCE AND THE WAR INDUSTRIES BOARD

(From a paper entitled "An Interpretation of the Engine Fuel Situation," presented by Joseph E. Pogue at the 1919 Annual Meeting of the Society)

on the fuel supply made by the motor truck, and the alarmingly small increase in fuel production to meet it. This surely means a shortage and increase in fuel price, and indicates the importance of fully considering chassis design from the standpoint of fuel economy. One phase of this concerns the average load on the engine. Motor truck engines under average service conditions do not operate with ideal economy even at full load; but how often do these engines operate under full load or anywhere near it? The engine in the average truck of less than 2½-tons capacity operates at about 20 per cent of full load when the truck is carrying its capacity load; larger trucks load the engine a little more heavily. When the truck is running light, or but partially loaded the engine is called upon for only 12 to 15 per cent of its

Digitized by Google

full load torque. Let us see what this means in fuel economy.

In Fig. 3 it is brought out that an engine at 15 per cent load is much less efficient than at 25 per cent and uses approximately 35 per cent more fuel. Fig. 4 shows a wider range of conditions and confirms this statement.

An even more fruitful field for saving, however, is that of carbureter adjustment. There are many truck carbureters that give the driver, a man without knowledge of the theory and practice of burning fuel in internal-combustion engines, the power to upset to a considerable degree the fuel economy we reasonably expect to obtain. He can tamper with the carbureter and almost invariably he will misadjust it. Not only does this result in a very considerable increase in the amount of gasoline consumed, but it can arbitrarily reduce the torque of the engine, overburden the cooling system, foul the spark-

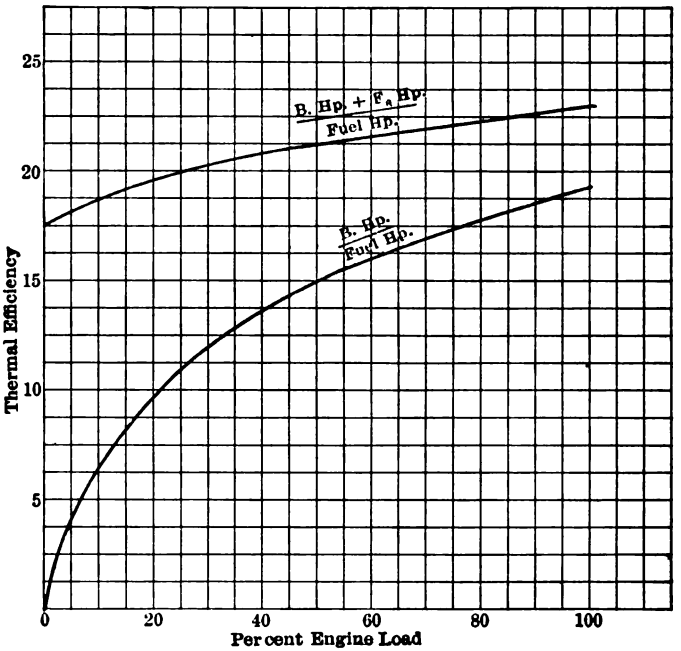


FIG. 3—CURVE OF THE THERMAL EFFICIENCY OF A CLASS B TRUCK ENGINE OPERATING AT 1000 R.P.M. AT VARIOUS PERCENTAGES OF LOAD

(From a paper entitled "Fuel Economy of Automotive Engines," presented by Dr. H. C. Dickinson at the 1919 Annual Meeting of the Society)

Digitized by Google

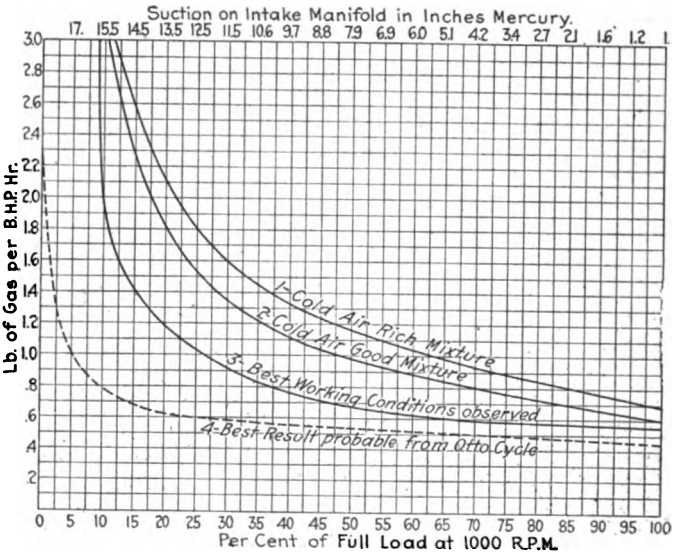


FIG. 4—FUEL ECONOMY OF DIFFERENT INTERNAL-COMBUSTION ENGINES AT VARIOUS PERCENTAGES OF LOAD AVERAGED FROM A NUMBER OF TESTS

(From a paper entitled "The Principles of the Wheeled Farm Tractor," presented by Edward R. Hewitt at the 1919 Annual Meeting of the Society)

plugs and cause serious delays and expense due to carbonization of cylinders and dilution of crankcase oil.

Fig. 5 illustrates an average condition vouched for by the Bureau of Standards and typical of a large number of trucks. It is interesting to compare these curves with the ones referred to previously. The possibilities of saving fuel become distinctly apparent. Fig. 6 brings out the same conditions converted into miles per gallon, a more familiar term to the owner. If we decrease the speed scale by one-half and double the consumption scale we shall have a diagram that represents truck performance. I can testify to raising the gasoline mileage of a certain model of 2-ton truck from an average of 6 miles per gal. to almost 11 miles without sacrificing the pulling ability or the flexibility in any way—bettering them, in fact.

The cost of tires is a large item in motor truck operation. It can be materially decreased by reducing total and unsprung weights, and bettering spring suspension.

Digitized by Google

In some instances tires are too small for the truck. There has been some tendency to apply narrower tires to save in first cost.

The driver's comfort has a good bit to do with the service rendered by the truck. We must therefore have good springs, easy seats, well arranged controls, protection from inclement weather and the minimum of details that require attention and care.

A careful and capable handling of the previously mentioned features will bring about a design of chassis that will permit of a high average speed. We can haul as heavy loads with horses or mules as with trucks, but the great advantage the truck possesses over animal-drawn vehicles is that of speed. How fast can the load be dedelivered and a return made for the next load? The perfecting of the "giant" pneumatic tire has made possible a considerable increase in maximum speed, and we are

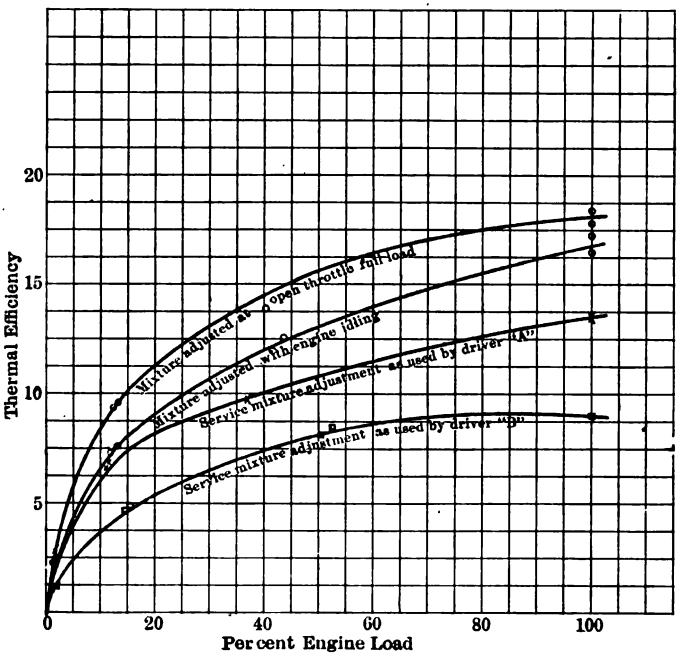


FIG. 5—THE THERMAL EFFICIENCY OF A FORD ENGINE EQUIPPED WITH A STANDARD CARBURETER AND USING DIFFERENT MIXTURE ADJUSTMENTS AT VARIOUS PERCENTAGES OF LOAD

(From a paper entitled "Fuel Economy of Automotive Engines," presented by Dr. H. C. Dickinson at the 1919 Annual Meeting of the Society)

Digitized by Google

bound to see this possibility developed. With the considerable increase of speed more attention will have to be paid to brakes and steering mechanism. However, it is the average speed that counts—not the maximum speed. A safe increase in maximum speed helps the average, especially on long hauls. But a far more important feature than maximum speed is that of keeping the trucks moving. No wasted time in roadside adjustments or repairs, or in the repair shop, or due to the neglect of some inaccessible part, to accidents resulting from an overtired driver, to expensive overhaul, or to failure of small details, which receive less design attention than they deserve on account of the large amount of thought and energy expended on main units, are desired.

The last general point upon which I shall touch is cost. Here it is more important to consider the cost of transportation by motor truck than the cost of the truck itself. The purchaser is only incidentally interested in the size and type of the various structural features entering into the composition of the chassis. What he wants is a piece of mechanism that will carry his goods for the lowest net cost and cause him the least worry. If manufacturing costs are reduced at the expense of any of the vital features of the truck, it is worth less to the buyer, and, in the course of time, he will discover it. One thing that some of our war work has done is to show how small a difference in cost exists between a thing well done and one nearly well done. If this lesson is heeded, if simplification is properly carried out, and the designs drawn so that some parts can perform a double, or sometimes even a triple, function, large cost reductions can be made.

In a paper delivered recently before the Society the chief engineer of one of our large companies placed cost reduction ahead of economy. He stated, "I must confess that in placing economy below first cost I am reflecting the buyer's attitude, as he, thanks to the manufacturer's reputation for never understating his case, will give greater weight to a known economy of first cost than to a promised economy in operation." Possibly more restraint put upon the sales and advertising departments would obviate this attitude, which is detrimental to the industry and the trade.

Now as to more specific features of the motor truck chassis.

Cooling systems leave much to be desired. The built-

Digitized by Google

up type of radiator with large gilled tubes, is very sturdy and reliable; hence its popularity. It is bulky, comparatively inefficient and costly. It imposes its extra weight on the frame ahead of the front axle, which makes for harder steering. Much improvement in average fan efficiency has been made in the last three years, but we can certainly go further in this direction. Fan location can be improved, and altogether I am satisfied that a very considerable betterment can be effected in our cooling systems.

Spring Suspensions

Spring suspensions have improved, but still offer a large field for advancement. The fact that they serve as buffers for the whole chassis above them, and that the life of the chassis parts is largely dependent upon the efficiency with which they function, warrants very careful study of everything pertaining to the spring suspension. The life of tires, also, will be favorably affected by

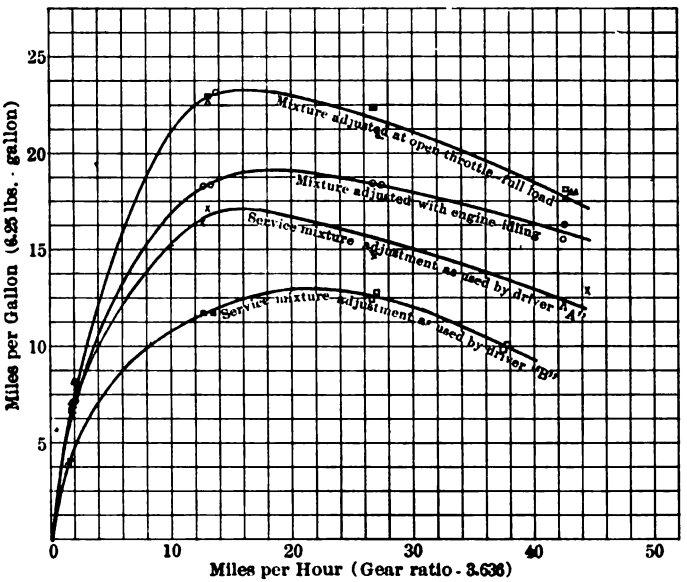


Fig. 6—Curve Showing the Relation Between the Speed of a Ford Car Equipped with a Standard Carbureter and Using Different Mixtures and the Mileage Obtained from a Gallon of Fuel

(From a paper entitled "Fuel Economy of Automotive Engines," presented by Dr. H. C. Dickinson at the 1919 Annual Meeting of the Society)

Digitized by Google

good springing. Longer springs, flat under load, are being generally adopted. We have not yet got the spring that will give us a much higher rate of deflection at light load than at full load. Some commendable efforts in this direction are being made, however, and the results will be watched with much interest. Springs which receive enough oil to keep the leaves from rusting and accumulating an excessive amount of interleaf friction have a considerable advantage, and the rapid increase in the use of oil as a spring-bolt lubricant will increase spring effectiveness.

Close attention to spring-bolt lubrication will pay big returns. Grease as a lubricant is doomed; it is only a semi-lubricant at best and a dirt carrier. When a spring opens up at the eye or breaks near it, the cause can almost invariably be traced to a bolt which has bound or chafed in the eye bushing. Many a grease lubricated bolt has had to be driven out of its bushing. Lack of good lubrication here contributes to hard riding. Most oil fittings on spring-bolts admit dirt and water. They are easily damaged or knocked off, and the scant attention paid to them by truck users has led me to a close study of these details for several years.

Fig. 7 shows a magazine oiling device for spring-bolts that has been in use on the Pacific coast for two years, and was incorporated in the Class B Army truck. The bracket casting is of a strong hollow section which forms an oil reservoir of unusual capacity. The feed is by capillary attraction through a good-sized wick which completely fills the tube and acts as a filter as well as a carrier. The oil feeds slowly under the influence of the vibration of the truck and the motion of the bolt in its bushing and ceases when these stop. A single filling will last from one to three months. Dirt and water cannot be fed to the bolt. The small surplus of oil flows down the spring leaves and keeps them easy and free from rust. In Fig. 8 the rear shackle is made hollow for the oil and is very strong, due to the box section; yet it is not clumsy looking and entails no extra machining except tapping the hole for the filler plug.

We have all been looking for a means of determining how good springs are. I quote from a letter which shows the value of good springs in a certain kind of service: "Packing houses in the fruit and vegetable district pay owners of trucks equipped with magazine oiling one cent more per crate for delivery than they pay for

Digitized by Google

the same hauling with other makes of trucks, as they claim that berries, etc., arrive in very much better condition when hauled by the lubricated spring trucks." This is a very practical demonstration of a direct commercial benefit due to attention to detail. A certain trade publication recently reported that a fleet of twenty-five trucks, similarly equipped, and handling ore over bad roads, showed a much better tire mileage than could be obtained with other trucks on this same service.

While on this subject of oiling of chassis parts, it may be well to call attention to the unsatisfactory manner in which most of our brake connections are lubricated. The effectiveness of brakes is often seriously impaired by the undue amount of friction almost always present in the connections, which wear badly and also rattle.

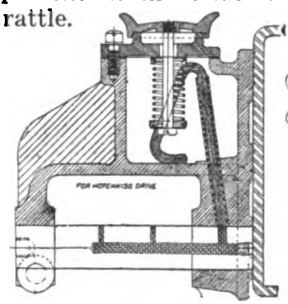
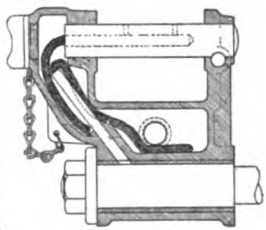


Fig. 7



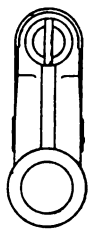


Fig. 8

Two Examples of Oiling Devices for Spring Bolts

The rocker shafts of the Class B truck were lubricated by the magazine wick system. As a rule not only is little provision made for lubricating these points, but they are so inaccessible that they get practically no attention. This feature of inaccessibility also applies to the rear axle brake parts, and a very considerable improvement can be looked for there. These should be magazine-fed so as to compensate for the lack of attention they receive.

The use of oil on front axle pins and on drag links is rapidly becoming general, as it should. There is room for improvement in detail here. A device for lubricating a universal-joint by a small amount of oil drawn automatically from the gearbox or rear axle, has been proposed and is being developed. It also feeds to the slip joint in the propeller-shaft where it is of great service in helping to eliminate the heavy thrusts against the bearings forward of the universal-joint.

Digitized by Google

The New York branch of one of our large truck companies has established a school for training drivers, and this school lays especial emphasis on lubrication. Every man attending is given an oil can and goes over and over the chassis until he has thoroughly learned the position of every oil cup, etc. Many a poor chassis that has been well lubricated by its driver has out-served better ones that were poorly lubricated or scarcely lubricated at all. I believe we can profitably keep before us the fact that practically all mechanisms depend upon a lubricant for proper functioning. The more automatic the lubricating means have become, the more successful and fool-proof have our mechanisms become.

In the matter of axles and wheels we have achieved great reliability at the expense of additions in unsprung weight. As a result tires have suffered. There is need for improvement in methods of fastening springs to axles. At present there seems to be a serious need of larger spring clips than are being used and better methods of keeping clip nuts tight. Much spring breakage can be traced to loose clips. Steel wheels for 3 to 5-ton trucks are making considerable progress, due probably to a scarcity of first-class wood for felloes. Steel wheels will be lighter, we hope, as time goes on, and wood wheels of better quality.

Gearbox design is in general fairly well standardized. However, the call for boxes having a ratio of high gear to low gear in excess of 4 to 1 is being heeded. I can remember laying out a chassis in 1911 and incorporating a four-speed box in which the low-gear reduction was 5¼ times the high gear. Two large builders of such units looked over the designs but could not see the necessity either for four speeds or for the large speed range; about 3.6 to 1 then being thought to be the correct range. The testimony given in many conferences on the Class B gearbox design and the splendid low-gear performance of these trucks, which had a speed range of about 6 to 1, has made apparent the value of the big range, and there is a rather general movement to take advantage of it.

Engine Size

Engine size cannot be considered without due thought being given to several other important characteristics. The horsepower necessary to drive a truck at a given speed being about in proportion to the total weight

Digitized by Google

moved, it will readily be seen how important is any reduction in chassis weight. In considering engine size the torque and maximum advisable rotative speed are the two important factors. With these must be correlated the various gear reductions, the diameter of the driving tires and the total weight moved. Six years ago and twice subsequently papers were read before this Society in which was given a tractive factor formula embodying these relations. Comparisons of American and French trucks were made, and specific applications of this formula were given. The substance of this formula was embodied in the specifications of the Quartermaster General's Office of the Army, now the Motor Transport Corps, covering Class A and Class B trucks. This formula can be written in two ways:

$$TF = \frac{\text{Engine Torque} \times R}{\frac{1}{2} D \times W} \times E_t, \text{ or}$$

$$TF = \frac{8.4\, n\, b^2\, s\, R}{D \times W} \times E_m \times E_t$$

in which R = gear reduction
D = diameter of driving tires in inches
W = total weight in pounds
E_m = ratio of torque developed by engine at 1000 ft. per min. piston speed, to the torque corresponding to the A. L. A. M. (N. A. C. C.) horsepower rating of the engine
E_t = efficiency of transmission system, engine to tires
b = bore in inches
s = stroke in inches
n = number of cylinders

Either of these can be of help in determining engine size and in producing a well-balanced design. They are also of use in making general comparisons of ability characteristics.[2]

In general, trucks of today are correct as to type and contain reliable units. Some are firmly established as at least the equal of foreign competitors, but the cessation of hostilities has left us with valuable experience and new opportunities. Our chassis design is capable of development and we shall refine many details. From now on I believe we are going to think of "service" not as something rendered from a garage to keep our trucks on the road, but as embodied in our product, which must be designed and redesigned, studied and perfected to

[2]See papers by the author on this formula in vols. 8, 9 and 10 of the *S. A. E. Transactions.*

Digitized by Google

every reasonable extent within our means before being sent out of the shops with our trademarks.

Good detail will do it. Detail that serves reliability, accessibility, simplicity, weight reduction, speed, economy of operation and cost.

The head of one of our important trade publication companies, returning recently from a trip through the automobile factories of England and France, was much impressed with the air of solidarity and permanency of these plants. He was also impressed with the refinement of design and the finish of the products. He set forth his views on these things in a call to American manufacturers to perfect the details of their product and set up standards of high quality. "Reconstruction is at hand," he states. "The world is entering on new conditions. American manufacturing enterprise must now evolve from transient and short-lived dividend production to an institutional, permanent and constructive establishment which will outlive its progenitors and establish the solidity of American industry in the future markets of the world."

That is not a criticism, but a call that I believe is already being heeded.

THE DISCUSSION

W. M. BRITTON:—Mr. Myers did not bring out fully enough the necessity for considering the tractive factor in chassis design. He has referred to a formula for obtaining tractive factors, but it would appear to the average man as being out of the ordinary. This is not the case. In fact, it is a very simple proposition, which anyone can readily understand, and which every designer must consider in working upon trucks or automobiles. It is simply a problem of determining the tractive ability of the vehicle. The gear ratio of the rear axle is known and so is the distance from the center of the axle to the outside of the wheel. Let us assume that the gear ratio is 8 to 1. Multiplying the torque of the engine in inch-pounds by eight, gives the inch-pounds torque at the rear wheel. Dividing this by the distance from the center to the outside of the wheel gives the tractive effort at that point. Then, by dividing the tractive effort by the weight of the vehicle, the tractive factor is obtained. In preparing the specifications for Government vehicles, the conditions under which the trucks must be operated were known, and it was necessary to specify the tractive abil-

Digitized by Google

ity of the vehicles in a very definite manner. At that time different kinds and sizes of vehicles were being bought and it was necessary to know something about what each vehicle would do.

Mr. Myers has referred to the cooling system of the Class B truck. It was provided with a fan shroud. In the design of this truck, the question came up as to whether or not a fan shroud should be used. Some of the truck designers and engineers claimed that it was not needed, and that they had conclusively proved by experiments that it gave no good results and was simply another complication. I insisted that the experiments which had been conducted be repeated to demonstrate the accuracy of their observations. When they were completed, all were of the opinion that the fan shroud is effective and that it adds very materially to the efficiency of the radiator. As a result of these experiments on the fan and the radiator, it was possible to use a decidedly smaller radiator than had been previously specified. It has been the customary practice to specify the cooling area of the radiator in proportion to the horsepower of the engine. In the Government specifications, the cooling area of the radiator in proportion to the piston-swept surface of the cylinder walls was specified, in other words, the circumference of the cylinder multiplied by the stroke, multiplied by the number of cylinders. This, I believe, bears a more accurate relation to the cooling area required than the method previously mentioned.

With reference to springs, it should be kept in mind that they can be too well lubricated. Springs are not polished carefully and oiled, and there is a definite reason for this. A leaf spring, properly constructed, is an excellent shock absorber. If it has too much oil it gives too much rebound and has no shock-absorbing effect. Just enough oil to prevent squeaking and rusting is desired.

I agree with Mr. Myers as to the use of oil for the general lubrication of trucks. Attention must be given to the wick in the device he mentioned. If the lower end is below the point of supply, or if the wick is loosely installed, the oil will continue to flow whether the vehicle is running or not. Small oil lubricators with wicks are satisfactory. Any kind of dirty oil can be used. The packing in the lubricator will screen out the dirt and good lubrication will result.

I wish to emphasize the value of low gear reduction in

Digitized by Google

transmissions. When we began to test trucks in Washington, one of the greatest difficulties was to make the truck builder understand that trucks for severe service must have low gear reduction. For commercial and economical use smaller engines, capable of high speed must be used. A high-speed engine should not be expected to pull heavy loads with a high-speed gear reduction, but it can be given just as good pulling characteristics as a low-speed engine, if a proper gear ratio is selected for the transmission and the rear axle.

The question of unsprung weight is very important and will militate very decidedly against the use of steel wheels of the present design. The use of well-constructed wood wheels is thoroughly satisfactory, and gives a lower unsprung weight.

A. L. RIKER:—I want to ask what happens to the oil at 10 deg. below zero?

MR. MYERS:—Heavy oil does not flow at zero temperatures, and it is not advisable to use a very heavy oil in winter. We should use lighter oil on account of the feature brought out by Mr. Britton. With loose wicks, however, a light oil feeds out under the influence of engine idling when the truck is standing still. If the wick is tight light oil can be used. The advisable thing to do is to use the same oil that is used in engines, light in winter and heavy in summer, in connection with snugly fitted felt wicks.

MR. RIKER:—Does the device work under all conditions and all the time?

MR. MYERS:—There is no such thing as never failing, but the magazine system does remarkably well. We have had trouble from the congealing of the 600W oil in cold weather, but found from experience that a little kerosene would loosen the oil up and give satisfactory lubrication. With grease, however, there is practically no lubrication whatever in cold weather.

In France the Motor Transport Corps of the A. E. F. used half oil, half kerosene and report very satisfactory results. A major well qualified by past experience to comment on such details writes

> The point about the Class "B" truck that impressed itself most forcibly on my mind was the automatic oiling of various chassis parts such as the spring-shackles and hangers, brake-control linkage bearings, universal-joints, steering-knuckle bolts, and other parts by magazines which supplied the oil to the bearing points by

Digitized by Google

wicks. These magazines could be filled with fluid oil, and a filling once a month was all that was needed. The cast spring-brackets were cored out and held a good quantity of oil. In cold weather the oil was thinned with kerosene and fed to the bearings through wicks without much difficulty. The kerosene cuts rust and carries enough oil with it to insure adequate lubrication of points usually neglected. Trucks equipped with the magazine oil feed were always better lubricated than those using grease cups, which were too easily lost, and besides, the grease passages were found to fill with mud. It would seem that this is a feature which all motor truck makers should incorporate in their chassis construction, since the author's experience would indicate that it is entirely practical in industrial as well as military applications.

Digitized by Google

TRACTOR MEETING

A highly interesting and well-attended meeting was held on Feb. 27 at Kansas City. The afternoon session was devoted to consideration of four technical papers dealing with the tractor industry from the testing, fuel and design viewpoints.

The first paper, which was on Tractor Testing, by Prof. J. B. Davidson of the California State Agricultural College, outlined the different field tests which it is desirable to make on tractors intended for farm use. Particular emphasis was laid upon the drawbar horsepower and the necessity for accuracy and a clear record of the data obtained. If the actual horsepower that a tractor is capable of delivering could be determined accurately and conveniently it would not be necessary, Professor Davidson explained, to provide for such a large reserve of power, and there would also be less overloading. In this connection he pointed out that it is not practicable to eliminate the horsepower rating and instead to express the capacity of tractors by the number of plows they will pull, because of variations in the size of the plow bottoms and fluctuations in the amount of power required to pull a bottom in different soils. The importance of a standard rating to the tractor industry was brought out in the discussion of the paper, and also the fact that the National Implement and Vehicle Association has been considering the subject of tractor ratings.

The second paper, by Dr. Joseph E. Pogue of the U. S. Fuel Administration, covered practically the same ground as the paper which he presented at the Annual Meeting of the Society in February. Dr. Pogue paid particular attention to the subject from the standpoint of the tractor manufacturer, and suggested the advisability of designing all types of automotive apparatus to use the same kind of fuel, which from the present outlook would of necessity be heavier than those now in use.

The last paper of the afternoon, which was presented by Prof. E. A. White of the University of Illinois, was entitled The Next Step in Agricultural Implement Design. In this paper, tribute was paid to the men who invented the principal types of agricultural machinery now in use. While for the most part they were not technically educated, they possessed genius, enterprise and

Digitized by Google

courage, and most of their work which was successful was done on a cut-and-try basis. For that reason their successors continued to follow in their footsteps and work by empirical methods.

Following the afternoon meeting a dinner was held at the Hotel Baltimore, at which Finley P. Mount acted as toastmaster. Among the other speakers were Dr. Pogue, who again advocated the use of a single standardized fuel for all types of automotive apparatus, thus utilizing the entire range of petroleum products that will burn successfully in all types of internal-combustion engines. He pointed out that this would mean cheaper and easier merchandising, as well as the securing of greater fuel value per gallon of crude petroleum. In addition he favored a further splitting up of kerosene with a view to reducing the quantity of that fuel and increasing the production of gasoline.

J. B. Bartholomew, the second speaker, stated that the division between motor and horse equipment is becoming more thoroughly defined each day, and that there will be eventually only two kinds of dealers: one selling tractors, and all the farm machinery to be used with them, and the other handling only horse-drawn machinery equipment.

David Beecroft gave an illustrated talk on his trip over the devastated areas of France and Belgium. E. A. Johnston also spoke.

ADDRESSES AT KANSAS CITY TRACTOR DINNER

Following the afternoon session of the Tractor Meeting at Kansas City on Feb. 27, a dinner was held at the Hotel Baltimore which was attended by 270 members and their guests. Finley P. Mount acted as toastmaster. The other speakers of the evening were Edward A. Johnston, Joseph E. Pogue, J. B. Bartholomew and David Beecroft.

ADDRESS OF FINLEY P MOUNT

It would seem that among the many problems which a tractor designer should keep in mind the first is the use to which his product is to be applied. If you

Digitized by Google

are about to design a tractor I respectfully suggest that the first question you should ask be: What is it expected to do; what kind of work is it to perform and what economies can be secured by the performance of that work with a power machine? The work of a tractor has become synonymous with farm work and, since the farm tractor is to be bought and used by the farmer, we should first know just what this work is, we must take a look over the entire farm for a year, and analyze and classify the work that can be done by mechanical power. We must also broaden our views geographically to cover the whole field of farming and include not only the one-purpose farm as found in the vast small-grain areas of the West, but the general-purpose farm with its diversity of crops and consequent diversity of work.

To my mind farm work divides itself, from the standpoint of a farm tractor, into three classes:

(1) Heavy-duty work, such as breaking ground, preparing the seed bed, drawing heavy loads, operating the haying and harvesting machinery in large or multiple units, pulling a grain separator, and the like

(2) Light-duty work, such as cultivating row crops, operating haying tools and harvesting machinery in single units, and doing all the light jobs on a farm ordinarily performed by from one to three horses

(3) Transportation over improved roads between the farm and the market of supplies to and products from the farm

In my judgment an all-purpose farm tractor, one to do well all the work on a farm, is a fundamental impossibility. It may be admitted in the outset that all of these farm jobs might be shot at by one type of tractor, but this cannot be done economically. The motorized farm will become a reality only when tractor engineers and manufacturers realize that it is not only worth while but an economic necessity to provide the farmer with a power unit for each class of work. One does not attempt to haul logs in a buggy, or drive to church on Sunday in a log wagon. The first is wholly impracticable and both would be uneconomical. Railroading is a big business, but not as big as farming; its problems of power are less intricate than the problems of power farming; yet it was not long before the pioneer railroads discarded the all-purpose locomotive, classified the work and built their power units accordingly.

Digitized by Google

Breaking ground and belt operations are the heaviest parts of farm work. To do this work successfully and economically the tractor must have excess power in its engine to meet readily and without strain the highest peaks of requirement in the way of heavy gumbo soils, hard dry-packed soil conditions, and varying grades of work.

The machine must be built to operate with perfect ease all the belt-driven machinery which any farmer may have occasion to use.

Too much cannot be said in favor of excess or reserve power in a farm tractor. The farmer has shown a natural tendency to overload his tractor. I believe that more troubles have arisen in the field on this account than from any other reason. Having started with such an engine, the transmission, frame, wheels and all supporting parts of the tractor proper, must be of such proportions that the engine will not tear them down under strain. Tractor engineers and designers should always bear in mind that there is no such thing as a constant load factor in breaking ground. The strains and added loads in plowing come suddenly, intermittently and everlastingly, and are superimposed on the ordinary load due to the draft of the plows pulled on level ground, in ordinary soil, at ordinary depths. It is the difference between a steady pull and a succession of jerks or blows. One may, of course, have whole areas or whole seasons when the load factor in plowing is practically constant and steady, but these areas and seasons go without rule and are likely to change during one month, in the same township, on the same farm. The designer who would succeed must meet the hardest rather than the easiest conditions. Finally, the whole machine must be heavy enough to give required traction. Lugs or grouters alone will not give it. Lightness is not the sole desideratum. When an engine will spin the well-groutered wheels of the tractor on which it is mounted, that tractor is as light as it ought to be.

Having produced the tractor that will do the work intended efficiently, there remains the big factor of economy. This does not mean fuel economy alone, but includes as well the answer to the questions: How long will the tractor stand up? How many seasons is it good for? How many plow-miles will it produce? On these points our knowledge is largely empirical.

There are certain elements which I believe are essential in a tractor for this class of work. These are slow

Digitized by Google

speed heavy-duty engines, two-cylinder type preferred; the fuel combination of oil, air and water so automatically controlled as to meet instantly each new condition of load; a spur-gear transmission mounted on the tractor frame, and wheels sufficiently strong and rugged to take all the strain put upon them by the engine without undue wear or breakage. The question of fuel economy is of course an important one. Tractors can be made which produce as much power on a gallon of kerosene as on a gallon of gasoline. Such tractors have been built and have been doing this for years, and since the cost of kerosene is ordinarily not over one-half the cost of gasoline, it is obvious that kerosene is the logical fuel for a farm tractor. A fuel cost of 45 cents per acre plowed is no uncommon performance. On this basis the plowing of 300 acres per year would amount to a saving of $135, and in a life of 10 yr. the saving would equal the entire cost of many tractors capable of doing this amount of work.

Our own experience has proved to us that this type of engine and tractor is economical in both fuel consumption and length of service. Admittedly this type of engine costs more to manufacture than a multiple-cylinder, high-speed engine of equal horsepower.

If tractor engineers, therefore, can design and build a farm tractor for heavy-duty work along the lines of the automobile type of construction and design, one which will in fact stand up, take the rough and tumble knocks and fights it will be subjected to, under all conditions of soil, seasons and service, and show actual length of life under these conditions and reasonable fuel economy, they will be conferring a real benefit on the industry as a whole. Scientific designing may produce such a tractor, but science can never be certain nor can it prove in advance of actual tests and length of service, that such a type of machine will be efficient and economical.

You can calculate to a nicety the strength of materials required for a railroad bridge; you can build a locomotive with a narrow margin of safety, you can design an automobile, and even build an airplane with correct provision for results, because you are dealing with factors known and reasonably within your control; but when you begin on a tool to dig into mother earth, you open up a field that is difficult of advance conjecture.

The second class of farm work which can be econom-

Digitized by Google

ically performed with mechanical power is a much simpler proposition. Here the light work of pulling a planter, a row crop cultivator, a single unit of haying or harvesting tools and the like, requires neither as much power in the engine nor as much strength or weight in the tractor as a whole. This type of machine could be designed to operate from the driver's seat on the tool drawn. The tractor must be light in weight and have high clearance because of its use in cultivating corn. Here because of the small amount of power required, fuel economy itself is of less consequence. Undoubtedly a lighter and higher-speed engine can be economically used on this type of machine. Because of the speeds which may be required of this tractor, and its general lightness in weight, spring mounting would not be out of order. Of course, when you leave the corn and cotton country and try to meet the requirements of the orchard, you must be prepared for further modifications in type.

The third and last job on the farm for mechanical power is transportation over roads. Here many new factors arise and the economy due to speed alone becomes more important than in either of the other types. Moreover, the character of the roads is perhaps the greatest determining factor. The tractor which operates on the farm in doing the plowing and cultivating jobs must be geared at a speed too low to afford economy as a transportation medium. If you add a high-speed gear to it to economize in time, you shorten the life of the machine. If the attempt be made to make up for lack of speed by increasing the load hauled, the necessary cleat or grouter equipment on the wheels of the tractor will be destructive to the roads, and will prevent the general use of farm tractors on good roads for such purposes. I do not believe the heavy-duty plowing tractor or the light-duty cultivating tractor will ever take the place of a light truck for road transportation. This type of machine is now pretty well standardized and needs no comment from a tractor manufacturer.

To the objection that this method of supplying power for the farm would require an investment in three different power units, my reply is that they will entirely supplant the horse on the farm. Their initial cost, though somewhat in excess of the initial cost of the horses they replace, will be more than offset by the saving in tractor fuel over animal fodder, and the life of the tractor should

Digitized by Google

be as great or even greater than that of the horse, while the saving in man-power effected, and the increase in crop production made available by the use of the tractor, remain to the operator or owner as clear profit.

There are several potent reasons why the farmer should use machine power. First, of course, is the shortage of help, which promises to become worse rather than better; second, land is becoming so valuable and will soon carry such high taxes that no man can afford to own it unless he farms it most intensively to get the greatest yield possible; he can no longer afford to devote a material part of his acreage to raising roughage and grain for horses. Finally, the food complication is not over; in fact, it has hardly begun. It will take years to get the food supply of the world back into balance, as in pre-war times, and by the time the effect of this war's destruction is ended, the added population of the world, increasing in greater ratio than food production, will create a demand that will require the American farmer to do his utmost for many years to come.

One other factor, it seems to me, is well worth the attention of the tractor designer, because it so directly affects both the manufacturer and the farmer, and that is the cost of the machine. Much can undoubtedly be done to improve the design of the tractor from a manufacturing point of view, and the methods of manufacture themselves, to lower greatly the cost of the machine without in the least detracting from its efficiency, economy or life. However, no tractor should be designed with a view to cost alone. Experience thus far has confirmed us in the belief that a cheap tractor is the dearest in the long run.

Upon these broad lines of development we can surely all lay aside our personal feelings and cooperate fully to the end that the farm tractor shall soon reach a reasonable stage of perfection and power farming take its rightful place in the business world alongside the other great human enterprises.

ADDRESS OF EDWARD A JOHNSTON

Most of us here are seriously interested in designing, manufacturing and selling tractors which will be satisfactory for the use for which they are intended. Our success, in my judgment, ill be equal only to

Digitized by Google

our ability to make them reliable, durable and efficient.

The tractor must be reliable. The period during which the farmer does his plowing, planting, harvesting and other work connected with the crops is limited; consequently his powerplant must be reliable in the average operator's hands, and operate under any and all conditions.

The tractor must be durable. It must stand up well under the heavy duty of plowing, harrowing and harvesting without too frequent delays for repairs, adjustments, etc., as these result in high operating costs.

The tractor must be efficient. The farmer who buys a tractor is not interested in the sort of efficiency that will save him $1 in fuel and cost him many times that amount in delay, maintenance, etc. Farming is a business like any other business. The farmer works for profit, and he will use the tractor only when he finds it is profitable to do so. He is not particularly interested in the number of its wheels. He does not care whether it has two or four cylinders, a horizontal or a vertical engine. He is interested only in getting a tractor with which he can carry on his farming operations and get results.

We must of course have standards as far as is practicable, but this need not be overdone. Standard belt speeds, drawbar ratings, tractor speeds, etc., will be useful, and in addition to these there are many automobile and truck standards applicable to the tractor which will result in enormous saving to both the farmer and the manufacturer.

We all have our pet theories and personal interests, but at the same time we are all interested in the successful development of the tractor. Any machine placed on the market and sold that does not prove satisfactory is a detriment to the tractor business as a whole. It is to our common interest to cooperate unselfishly to the fullest possible extent in producing tractors that will be satisfactory to their purchasers. There is much to be done to improve ignition, carburetion, lubrication, etc. Let us put forth our best efforts to design and manufacture tractors that are reliable, durable and efficient.

ADDRESS OF JOSEPH E POGUE

Mechanical tillage constitutes a third of the food problem, but an important third. The horse and

Digitized by Google

the mule are destined to pass in large measure. They represent an internal-combustion engine consuming high-priced fuel useful otherwise as food, running 24 hr. per day whether used or not, and low geared, with a capacity at best only 3 to 4 miles per hr. In place of the horse and the mule comes the tractor. The tractor for farm use is a recent development and the growth in its utilization during the past few years, especially in the Middle West, has been great.

Coming into play at a time when the national food problem has taken on a world-wide aspect, the tractor assumes the utmost present importance, while the future calls for an extension in its use such as can be expected to largely relegate to the past the old-fashioned methods of hand-power and horse-power tillage. Indeed, upon the growing use of mechanical power upon the farm by means of the tractor, the motor truck, the stationary engine and the automobile—all dependent upon a cheap and adequate supply of engine fuel—the food supply of the future turns.

Farm work must be made more agreeable and more efficient if an increasing population is to be fed. Fertilizers and tractors under organized cooperative effort spell the solution to the food problem. The adequate development of tractors would appear to depend primarily upon two factors; the growth of cooperative farming and the cost of tractor fuel. If fuel prices rise unduly, the cost of tractor operation will limit the possibilities of tractor utilization.

Tractor design is still in its formative period. Its engine and its carburetion system are still in flux. The tractor can select its own fuel. It is vitally important that tractor evolution should follow the path leading to maximum fuel economy. Now is the time to determine this matter. Shall it be gasoline or kerosene or a mixture of the two? Distillate or alcohol? Shall it be a gasoline engine or a Diesel engine, or else an intermediate type? I cannot answer these questions at the present moment, but I believe that they will be answered after further study is given to this issue. It can be said, without undue exaggeration, that the whole tractor future hangs upon a happy selection of fuel by the tractor industry. It would appear, however, that tractors, along with automobiles and motor trucks, must work in the direction of using a less specialized fuel than at present, gasoline or kerosene, and at the same time develop a greater degree of fuel

Digitized by Google

economy than at present. If the automotive apparatus can adapt itself to this end, it will mean that the fuel of the future will be provided at a lower production cost, which means a lower price, than if the automotive apparatus holds out for its present low standards of fuel economy and highly specialized requirements as to fuel.

There are two problems which stand out in this connection, or rather two conditions which create these problems. In the first place, it is much easier to standardize the automotive apparatus than it is to standardize fuel. This means that if the automotive apparatus is rigidly standardized, as it must be, fuel will periodically tend to get out of adjustment with the apparatus. That is to be expected. In the second place, the automotive industry is growing more rapidly than means in sight are developing for providing engine fuel. This leads to the presumption that a shortage, or let me say an engine-fuel stress, may ultimately be expected, reflected in a rapid rise in fuel price. Both of these problems can be solved; but not without the active participation of the automotive industry, which includes, of course, the three major branches of automobiles, motor trucks and tractors.

In conclusion, then, an analysis of the fuel situation seems to show that in the future an engine fuel at favorable prices will be forthcoming if the automotive industry works toward greater thermal efficiency and shapes its development so as to handle a less specialized fuel than it is handling now.

ADDRESS OF J B BARTHOLOMEW

The situation as I see it from the business side is like this. There will be no going back. I have heard a good many people use the phrase "When we get back to normal conditions." I think there are many who have thought we would drop back very suddenly in the year 1919 to normal conditions or at least to conditions as they were before the beginning of the war. We are now approaching the opening of the season. The rush is soon to be on, but I do not believe you are going to have what is referred to as "normal conditions" for a good while. The dealer and the farmer who are waiting for that will be disappointed. The farmer will wait until he is ready to use his tractor and then may not get it. The dealer who is holding off is losing his opportunity.

Digitized by Google

This has been my belief for some time past; but if I am mistaken, if we do revert to something like past conditions, there is no reason why we should hold back now. Things should go ahead. We may have to go through a few seasons with rather narrow margins, but we shall not be any better off by simply sitting idle and doing nothing.

Much has been said about who is to be the ultimate dealer to handle tractors. This is no time to argue over the question whether the tractor trade belongs to the automobile dealer or the old-line machinery dealer. No matter where the tractor dealer comes from, what enterprise he may leave for this field, whether he has ever had any business experience before, I believe it will not be more than 5 yr. before the selling of agricultural implements will be divided into two very distinct sections, one under control of the hardware or horse-drawn implement dealers and the other under the tractor and tractor-drawn implement dealers. Occasionally one dealer may be big enough to cover both fields, but he will separate the two lines very sharply while managing both.

The tractor and tractor-drawn implement industry is going to be very interesting. It will undoubtedly be very fast, and will require special organization, new methods and training for a large amount of work in the fields. The old lines of horse-drawn implements and hardware will be carried on more or less as they have been, with perhaps a little canvassing in the country, but the bulk of the business will be done at the store.

ADDRESS OF DAVID BEECROFT

Fifteen of us were invited to the other side as guests of the British and French governments to reestablish relationships in the business world. During the period of the war the censorship and the restrictions due to the war had built up barriers.

We went through the great area of Chateau Thierry and to Rheims and Soissons. In the city of Rheims we got a vivid idea of what the Germans had done. They had been on the outskirts of the place since 1914. It had been a beautiful city of homes set on a great plain in the midst of vineyards, the houses set back in green yards with ornamental fences and great posts along the front. The posts are gone, the homes are destroyed. Into the

Digitized by Google

great cathedral the Germans are said to have dropped a shell every day. The French say the Huns used it as a target for their artillerymen. We were glad to find that the pillars stand uninjured. There are great holes in the roof, the exterior is all destroyed, but the great structure still stands.

The wine cellars at Rheims are now one great underground system and at one time there were 60,000 soldiers in them. They stretched barbed wire across the passages and entrances; the machine guns were still in position on their mounts and the beds of the soldiers still in place. Then we realized how it was that the Germans, although they got to the very outskirts of the city, were never able to reach its center. They say that if Rheims had ever been taken, the final fight would have been in those great caves so far under ground.

Verdun is the immortal battle ground of Europe. The French are glad to tell how it has been a great citadel since the days of the Romans; how it is one of the great bastions that protect the front. In this citadel they kept 60,000 troops, and baked all the bread for the men out in the trenches. They could take the provisions and men out to the trenches and bring back the wounded and the ones on relief protected from shell fire.

We went from there out under the hills into Fort Deulemont and Fort Vaux. The latter is on the edge of the hills, and, as you will remember, held out wonderfully in the fight of 1916. The great drive on Verdun started on Feb. 21 and the Germans took Fort Deulemont in a few days, but Fort Vaux, which is not over a mile away, they did not get until about June 23. That tells the story of the 500,000 Hun and the innumerable French dead. When we got into this fort we found hills again, and in these were great ramifications of arcades. We saw the guns 60 ft. below the surface, and up on top of these great craters, one 40 ft. deep, but still the masonry underneath had not been reached and was uninjured. They say that Fort Vaux would never have surrendered had provisions not run out.

Then we went to the city of Arras where the British made the wonderful fight against the Germans. Here they tell another story of how they used the underground system. Arras is built on a white chalk hill, and the buildings are made from stone excavated from beneath the city. The result is that under the entire city are cellars which had never been used. In the early days

Digitized by Google

of the war the British moved all their soldiers into those places, and, breaking down the walls between one building and another, connected and fitted them up. When the Germans got to the market place in the center of the city, 20,000 British troops were but a few yards away from them and were able to drive them out. While the place was not entirely destroyed, not a soul is living in the houses now.

Our hosts were anxious that we should see some examples of Hun warfare. One city, Douai, was never bombarded; it passed into the hands of the Germans in 1914, and they held it until September, 1918, living there with the citizens. In September an order came for the civil population to move out. Two weeks later the Germans had to move out. I will give you one example of what was to be seen all over the city. We went into one home, the home of a doctor. It was a typical fine home of Douai. This doctor, all during the period from 1914 up to September, 1918, had been in charge of Red Cross work under the instructions of the Germans. We saw on the door the Red Cross insignia and the official orders. He had lived there with his wife and children, and the head of the German Red Cross had lived with them. When this doctor came back to his home, this is what he found. In that beautiful house everything was destroyed. It was a five-story building with front and rear parlors. Every picture, and he had many fine ones, was cut out of its frame. The frames were thrown over into a corner. In the parlor he had a beautiful carved table; an axe had split the top in several places. There was not a piece of furniture left whole. The backs or legs of chairs were broken; the buffet in the dining room with heavily carved doors had both the doors split. The fine carved mantlepiece was marred as if struck by an axe. We went up to the bedrooms and found the bedclothing all gone, the fabric had been cut off the mattresses, and feathers were strewn over the rooms 7 or 8 in. deep. All the drawers had been pulled out of the dressers and upset in the middle of the room, and in most cases the fronts of the drawers were broken. The window shades were gone, and we could see how the draperies and poles had been pulled down. We went through every room in that home, and there was nothing but desolation and destruction; and in the fifteen or twenty other homes that we saw it was the same. In a little butcher store at the corner of the canal they had split

Digitized by Google

the wooden box in which he had kept his meat; also the counters; the meat block in the center was upset and the legs broken. There was nothing in that humble shop that was not destroyed.

Some of you no doubt remember the story that Private Peat told in this country a year ago. He asked a German officer whom he had taken prisoner why they had cut down the trees, maimed the children, destroyed the homes and everything else possible. His answer was, "Oh, that's quite natural. When we retreat over an area we leave nothing. We leave no tree that can be used as an observation post, or a shelter or other point of vantage. We leave no house that will shelter anyone. We leave nothing."

In Lens not a building is standing where there had been a city of 30,000 people. On either side of the road we passed every half mile the great coal mines. There were steel structures and wrecked buildings all along the way, and although the homes were not destroyed, every door had been taken off and the framework of the windows taken out.

We went along roads where there were machine-gun locations of heavy reinforced concrete, with the familiar little loopholes for the gun every 20 or 30 ft. Some of the churches were without roofs, but all the pillars were standing in perfect shape. Occasionally one is used as a hospital.

I think we must all feel that although the armistice is signed and peace will soon be made, our work in this war is not ended.

Digitized by Google

TRACTOR MEETING PAPERS

GAS TRACTOR TESTING

By J B Davidson[1]

THE objects to be obtained in testing tractors are listed, but field testing only is dealt with. Regardless of the attempt of the Society of Automotive Engineers to standardize the practice of drawbar horsepower rating of tractors, the practice followed by the industry is anything but uniform. Drawbar horsepower actually developed in tests at the 1918 National Power-Farming Demonstration, varied from 50 to 200 per cent of the rating. The need of more than 25 per cent reserve, as provided by S. A. E. Standard Practice, is argued. Drawbar pull is suggested as an important part of the rating. Rating of tractors by the number of plows pulled will not be satisfactory, owing to wide variation in soil conditions.

To make satisfactory tests an accurate dynamometer is required. The Hyatt and Iowa instruments are described. The importance of care in making tests is emphasized. In the discussion, the Gulley and Giddings recording dynamometers are described.

In the testing of gas tractors, as with any similar undertaking, it is best to determine clearly in advance the object to be attained. As analyzed, tests may be made for several distinct purposes, as follows:

(1) To determine the best adjustment of certain working parts, such as ignition, mechanism, valve timing, etc.

(2) To determine the distribution of the total heat obtained from the combustion of the fuel to useful work, to the cooling system, to radiation, etc.

(3) To determine the power output, first, of the engine in brake horsepower, and, second, of the tractor in drawbar horsepower

(4) To determine the endurance of the tractor

This paper is planned to deal only with field testing, or the determination of the drawbar horsepower, the lat-

[1]Professor of agricultural engineering, University of California, Davis, Cal.

Digitized by Google

ter part of the third class of tests. Inasmuch as tractors are used more largely for traction purposes than for any other, it is obvious that the capacity of the tractor in drawbar horsepower is one of much importance. It is one important element of the value sold and purchased, and any test or procedure which will determine this element with accuracy is worthy of careful consideration.

Standard Drawbar Horsepower Rating

The Society of Automotive Engineers has decided that as a matter of standard practice drawbar horsepower rating shall be based upon an actual test extending over 2 hr. on a firm traction surface. It is very clear that the present practice in rating followed by the tractor industry is anything but uniform, and must necessarily

A Recording Dynamometer Attached to the Drawbar and Ready for Use

be very confusing to the purchaser. The best evidence of this is furnished by the tests made at Salina during the 1918 National Power Farming Demonstration. These have not been made public, but in general show that for the forty-two tractors tested the drawbar horsepower delivered in actual tests varied from 50 to 200 per cent of their rating. Where such a condition exists the purchaser may be expected to be skeptical of tractor ratings in general.

The manufacturers of high-class tractors may be expected to welcome any development which will bring

Digitized by Google

about uniformity of practice, since less sales effort will be needed to prove, disprove, and argue. To those who desire to overrate their product it is obvious that tests to prove capacity are very undesirable. If manufacturers are not able to bring about uniform methods of rating capacity, purchasers will sooner or later ask for it.

It may not be entirely out of place to discuss drawbar horsepower rating. Uniformity in practice is undoubtedly the most important consideration, yet a logical and practical basis for rating is worthy of careful study. This rating should represent a normal, full or average working power output under normal conditions. The 25 per cent reserve provided by the S. A. E. standard practice is not sufficient to care for the variations in field load, due to changing soil conditions or grades. In other words, it is seldom possible to give a tractor a load which will enable it to develop its rated drawbar horsepower continuously, because it does not have sufficient reserve to care for the ordinary or common variations in load. A large reserve would be desirable for two different reasons; first, there would be less trouble from overloading, one of the most frequent causes of trouble; and second, the purchaser would not need to discount the rating in comparing a tractor with horse labor. In other words, it would be better either not to have any reserve or to have a sufficient amount to make the tractor comparable with horse labor.

With an increase in field and road speeds for tractors, for which there are some unanswerable arguments when conditions are favorable, the drawbar pull should be as much a part of the rating as the horsepower rating, for this pull determines the size and character of the implement drawn. The rated drawbar pull should be determined by a standard test and made a part of the tractor rating.

The proposal to do away with horsepower rating, and rate tractors in terms of the number of plows drawn, would leave us with the most haphazard system of all, for the reason that plows are not operated at a uniform depth, and the draft of a given size of plow, plowing at a uniform depth, will vary 200 per cent under different soil conditions.

It will be a comparatively easy task to educate the tractor purchaser to understand a tractor rating system, provided it is universally adopted, placed on a logical

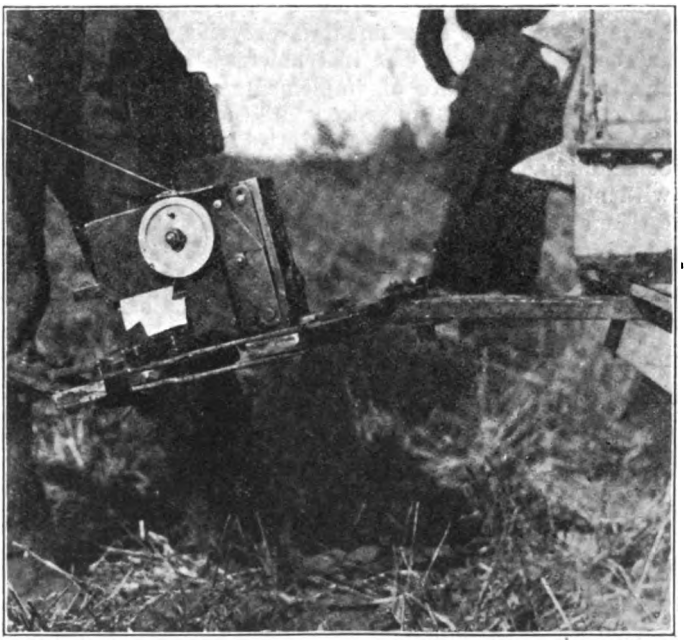
Digitized by Google

basis and faithfully carried out. In fact, there is now evidence of a demand from purchasers for such procedure.

Tractor Testing Instruments

In making a drawbar horsepower test there are two considerations of fundamental importance—accuracy and a clear, complete record of the conditions involved. The testing of tractors is too important a matter to permit of other methods than those which will give extremely accurate and reliable data. This is easier said than accomplished, because of the rapidly varying field conditions. A direct-reading dynamometer for determining the drawbar pull is practically worthless, on account of the wide and rapid fluctuations in draft due largely to the load but in part to the tractor. For this reason, a recording or integrating instrument must be used.

The Hyatt dynamometer is quite generally known and represents the recording type. A graphical record of the drawbar pull is obtained on a circular chart driven by a



A Dynamometer of the Integrating and Recording Type Attached to a Tractor Drawbar

Digitized by Google

ground wheel. The record is made by a recording pressure-gage unit connected by a flexible tube containing liquid to a compression unit of the diaphragm type receiving the full drawbar pull. Minutes are recorded automatically on the record. The average drawbar pull is obtained by going over the record with a planimeter or other instrument.

The Iowa integrating and recording dynamometer receives the load either directly or through multiplying levers on a compression spring. The recording and integrating mechanism is operated by a thread attached to a fixed point while the test is being made. The test is made after the tractor is in operation and conditions become constant. The mechanism measures a fixed distance automatically and with great accuracy. A graphical record of the drawbar pull is recorded on a strip of paper which shows the variations in full and may be averaged by a planimeter. The instrument, however, is arranged to give a number proportional to the average drawbar pull for the measured run, by a recording wheel carried across the face of a friction disk. This average when the instrument is properly manipulated is extremely accurate. The instrument is especially useful in testing the draft of implements and was designed primarily for that purpose. Its design is based on the theory that a short accurate test, with all conditions constant and known, is more valuable than a longer one with many variations.

The argument has been advanced that it is undesirable to use a spring to receive and measure the drawbar pull. Attention is called to the fact that a spring, or the elasticity of suitable material, is the only practical means of measuring the force acting under the conditions, and it makes little difference whether it is used directly or indirectly.

The S. A. E. standard practice for drawbar horsepower rating calls for a continuous 2-hr. test. This is no doubt based upon the theory that 2 hr. is required to determine whether the tractor has sufficient endurance and that all parts will function continuously. However, no instrument has been designed to average or record the drawbar pull for this period. There are no difficulties, however, in arranging such an instrument, and if the 2-hr. period is to continue as the standard test such an instrument should be designed.

Again, it should be emphasized that much of the value

Digitized by Google

of tractor testing depends upon the care with which the work is done, as when hastily performed it is of little or no value. Each test should be so carefully made and the conditions so accurately recorded that the results can be compared with other similarly conducted tests wherever they may be made. No small amount of tractor testing has been carried on in connection with tractor demonstrations. There are some advantages in having a number of tractors collected at one point where tests can be made under uniform conditions, but the hurry and excitement of a demonstration are serious disadvantages to overcome. If tests are to be made in connection with demonstrations, the management should give those in charge of them time to prepare and organize for their proper conduct. The competitive principle is undesirable because the final deductions or balancing may be in error. A better method is to make each test so that it can be easily compared with recognized standards of performance.

There would be greater interest taken in testing on the basis just proposed. It should be possible to arrange this through the cooperation of unattached and public service engineers. Without question it will make for the advancement of the tractor industry to establish definite records of performance.

THE DISCUSSION

CHAIRMAN E. A. JOHNSTON:—The standardization of tractor ratings is probably the most important subject before the industry today. Many States, in their legislatures and agricultural colleges, are agitating standardized rating to protect their citizens, and have some recognized means of comparing ratings that will apply to all makes of tractors.

PROF. E. A. WHITE:—I would like to call Professor Davidson's attention to the fact that there is a dynamometer on the market at the present time suitable for recording the drawbar pull of a tractor for a period of 2 hr. or longer. The Burr Co., Champaign, Ill., has for 15 or 20 yr. been perfecting and building railway dynamometers. It is recognized among mechanical engineers as the leading authority on dynamometer construction in the United States, if not in the world. It has already perfected a traction dynamometer suitable for recording time, distance, drawbar pull and total work for any test from 10 sec. up. There is absolutely no limit but the num-

Digitized by Google

ber of reels of paper you want to put on. It makes a horizontal record and gives evidence of being a machine for which the tractor industry has long been waiting. One of these machines was tried out by us last year in a series of plow tests which we have been conducting at the University of Illinois, and gave excellent satisfaction. The new tractor dynamometer, which is just now being put through, has a drawbar capacity ranging from 1 to 10,000 lb. It is a machine built upon the hydrostatic principle, has a dynamometer unit and transfers the pressure to the recording apparatus through oil.

CHAIRMAN JOHNSTON:—The National Vehicle & Implement Association's Tractor Division, the American Society of Agricultural Engineers, and this Society, are all very much interested in this subject. We may talk for years about arriving at a fair standard, but unless we get together and actually take some action to decide the question, the States will decide for us, and if we are not careful we shall have a different standard for every State.

MR. DAVIDSON:—I recall that the Giddings recording traction dynamometer, an instrument standardized for many years, is now being made with 2-hr. and longer charts. In line with the suggestion of the last speaker, would it not be possible for the officers of the Society to take steps to form a coalition committee with the American Society of Agricultural Engineers and the National Implement & Vehicle Association's Tractor Section? Such a committee could be commissioned to proceed at once to prepare and recommend standard practice regulations for the testing and rating of tractors.

Digitized by Google

AERONAUTIC MEETING

At the meeting in New York City on March 7, in the first paper, entitled Commercial Future of Airplanes from an Engineer's Standpoint, by C. H. Day, it was pointed out that constructional changes were necessary to adapt the war-developed planes to commercial use, the most important being that which will permit landings to be made at a relatively low speed without sacrificing the desirable high flying rate. The ability of a plane to rise from or alight upon a small area will, of course, exert considerable influence upon the practical use that can be made of an airplane. Another point upon which emphasis was laid was the securing of a less delicate type of engine, Mr. Day's opinion being that an air-cooled unit weighing the same for the amount of power developed as a water-cooled engine with cooling water, would be much stronger and more durable, as well as cheaper to manufacture. The use of twin engines, even for the small sizes of plane, was recommended, as it is possible for the pilot to maneuver such a plane on the ground in high winds without the help of a gang of men to set it in the proper direction, while greater safety can be secured in flight than with a single engine. An additional argument in favor of twin engines for larger airplanes, particularly those designed for passenger traffic, was the greater comfort that could be secured for passengers.

In the second paper, by Ladislas d'Orcy, which was entitled The Case for the Airship, considerable information as to recent performance of airships was given, showing that their development in war had been little less than that of airplanes.

The third paper of the afternoon, on Airplane Radiators, was presented by Archibald Black. This paper, which was of a very different character from the other two, contained a large amount of data dealing with the efficiency of several types of radiators, the effect of various mountings on the airplane, and other factors of importance.

At the evening session addresses were delivered by Col. V. E. Clark, Commander J. C. Hunsaker and Brigadier-General William Mitchell. The first two dealt with the development of aircraft for the Army and Navy

Digitized by Google

respectively, while General Mitchell's address dealt with the tactics of airplane combat. He told of the operations of our aircraft at the battle of St. Mihiel.

COMMERCIAL FUTURE OF AIRPLANES FROM AN ENGINEER'S STANDPOINT

By C H Day[1]

A BRIEF history of the engineering development of the airplane from the time of the earliest supposed attempt at flight, about 400 B.C., is presented and the effect of the war on the development of commercial airplanes considered. Other discussions include such items as safety, initial cost, cost of upkeep and cost per ton-mile; why devices for increased stability are not of great importance; the importance, for both safety and low cost, of machines that will allow landing in and flying out of small fields, requiring low landing speeds, a quick stop after landing and good climb for low speeds of advance. Suggestions are made as to means of accomplishing the requirements mentioned. The relation of proximity of landing fields to reduction of cost per ton-mile is stated.

Other considerations are size and type of commercial planes; the limitation of size; advantage to be derived, as to both safety and cost, from engines that will maintain their horsepower at great altitude; advantages of the tractor and twin-engine types of airplane; limitations of existing types of engine for commercial work; the importance of the development of less expensive and more reliable engines; and the possibilities of air-cooled engines for small airplanes.

The earliest attempt at a heavier-than-air machine, which we find reference to, is that of Archytas, a philosopher of Taranto, who lived about 400 B. C. The first man to whom we are indebted for approximation to the true principles, as known and written of, by himself, is Roger Bacon, an Englishman, born at Ilchester, 1214 A. D. His great wisdom seems even more marvelous in these days, since within the past century we have realized many of the ideas set forth by him. The flying machine, or means of mechanical flight, which has

[1]Chief engineer, Standard Aircraft Corporation, Elizabeth, N. J.

Digitized by Google

since made great strides, was written of and investigated by him. The art of mechanical flight, or at least the method by which it has been accomplished, seems to have been well understood by him.

Of those who have been mentioned, however, none has left us so much tangible information as has the artist, Leonardo da Vinci, the noted painter and sculptor, who was born near Florence in 1452. Besides being a great artist in painting and sculpture, he was equally as good a mathematician and engineer. His calculations, drawings and his deductions based on flights of birds, about which he has written considerable, are nearly modern in their accuracy.

Beginnings of Present-Day Machines

The flying machine, as we know it today, had its real beginning in the year 1810, with the experiments of Sir George Cayley, who analyzed the mechanics of flight and conducted experiments with gliders and spent his time experimenting with surfaces to determine their relative lifting effect when set at various angles of attack. He was also the first to suggest the use of a tail as a means of longitudinal stability and to show how the pivoting of the tail would enable it to be used as an elevator.

Following this, Henson was the next to devote much time and energy to the constructon of an airplane. He made use of much of the data worked out by Sir George Cayley. His machine, which was not built until 1843, was invented in 1835. It was a typical example of the monoplane construction as employed today, and among other things that are worthy of mention are the hollow wooden struts which he used, and double surface wings, method of tightening wires and landing wheels; he was probably the first to use a vertical rudder for lateral directional control. This machine was designed to be driven by a steam engine, which drove two propellers extending to the rear of the wings.

We are told that, in 1864, Wilhelm Kress of Vienna, Austria, commenced to experiment with small models as well as propellers and in that year built a model about 3 ft. across the wing tips and after many experiments and tests finally constructed a model in 1877 which was driven by rubber bands and actually rose into the air and flew for a short distance. He later built models with two and three planes, placed one behind the other, and also placed one above the other. In 1879 he took out

Digitized by Google

patents on his machine in many countries. On account of the lack of proper motive power he did not attempt to build a large machine until 1901, when he completed one weighing 1870 lb., with a total surface of 1011 sq. ft. He was destined to disappointment because the engine he used, which had been represented as one of 30 hp., did not develop the necessary power, and the machine was wrecked.

Among those particularly worthy of mention in connection with the engineering development of airplanes are Wenham, who built the first monoplane glider in 1866; Stringfellow, who built a steam-driven model airplane in 1868; Tatin, who in 1879 built a compressed-air driven model, and Hargrave, who built a box kite which was noted for its remarkable stability.

In 1893 the first wind-tunnel experiments were commenced by Philips, to whom we are indebted for many of the data which were useful for years after his time. And even now his data on wing curves are valuable, and the well-known Philips' entry, used on many curves today, is one of the evidences of his successful effort.

In finally placing the date of the actual starting of the investigation which ultimately rendered human flight possible, we must turn to the years 1888 and 1889 when the following men, though in different parts of the world, set themselves simultaneously to find the practical solution of mechanical flight. These men who are credited with this worthy task were: Professor Langley in America, Maxim in England, Lilienthal in Germany, and Hargrave in New South Wales. The more recent progress of the Wright brothers, Curtiss and others is of course to be noted. The admirable engineering advancement accomplished by these men is already known to all. Since then progress has been rapid and sometimes radical; many theories have been exploded and many more have been proven correct. The advancement made in engineering in the past is only a prediction of the possibilities of the future.

For the past few years practically the entire attention of the engineering talent of the world has been concentrated on the designing of airplanes exclusively for military purposes, and it is now necessary that serious thought be given to the design of purely commercial vehicles. The development of military airplanes has given us a great amount of extremely valuable engineering data, but not all the efforts of the past to obtain

Digitized by Google

enormous speed and climb at whatever sacrifice of initial cost and cost per mile are of great avail for commercial needs.

The commercial airplane of the future will be used foı sport and the carrying of mail, passengers and express. All of these things are now being accomplished successfully but in a limited manner, and the extent to which the field of usefulness will be increased depends largely upon the ability of engineers to develop machines better suited to the purposes than those we now have.

Factors To Be Considered

Of paramount importance are the questions of safety, low initial cost, low cost of upkeep and low cost per ton-mile. A great deal of attention has been given to devices to increase the stability of the airplane with an idea that this will greatly increase its safety. I do not believe that the development of such devices will greatly enhance the future of the airplane. The ease with which pilots have learned to fly existing training machines would certainly indicate that the stability of these airplanes is sufficient for present needs, and investigation will show that the majority of accidents have been due to either collisions in the air or bad landings, and not to any inability of the pilot to control the actions of the machine. The stability of these machines can be increased to almost any extent desired at very little sacrifice of efficiency. In fact, it is perfectly feasible for any aeronautical engineer to design a machine of any type with the surfaces proportioned and arranged so that the machine will be self-righting under all conditions; will not tail-spin unless forced to do so; and will come out of a tail-spin of its own accord. With the rudder fixed such a machine will fly almost indefinitely with all controls released and in case of engine failure assume a natural gliding angle and maintain that gliding angle until it reaches the ground. With good air conditions it would even make a safe landing if the ground were suitable. I might add that there are absolutely no mysteries connected with the design of a machine to accomplish these results. While riding as a passenger in such a machine two years ago I saw all of these things demonstrated in flight.

To my mind the most important development will be that which will enable airplanes to land in extremely small fields, or literally in a man's back yard. This

Digitized by Google

must be obtained at not too great a sacrifice of high speed. At the present time the load carried on an airplane which has sufficient reserve power for safe flying is about 20 lb. per hp., and a speed range of from 45 to 90 miles per hr. is now obtainable with this loading. It would, therefore, seem that the future airplane should be able to maintain a high speed of 90 miles per hr., speed being one of the main advantages of the airplane over other means of travel.

Among the possible means for reducing landing speed without sacrificing the high speed is the development of more efficient airfoils, devices for increasing the camber of the airfoil in landing, increasing the surface of the main planes, and possibly the development of an angular propeller thrust or auxiliary propeller to reduce the load per square foot of surface. Landing gears having greater shock-absorbing qualities to allow of stalling into a field from a greater height than is now possible would also help greatly. Airfoils having a high lift at high angles with low resistance at low angles, and which still maintain a good lift-drift ratio at normal angles, greatly reduce landing speeds and usually allow of maximum climb at low speeds. It is very probable that the efficiency of the airfoil will be increased to such an extent that any increase of camber would be of little benefit.

With relation to the use of angular propeller thrust or auxiliary propellers, it should be noted that with machines carrying 20 lb. per hp. not more than 50 per cent of the power is necessary for sustained flying at very nearly the airplane's lowest speed. It certainly would be highly advantageous if the 50 per cent excess horsepower available at this point could be utilized as a vertical component to reduce the loading per square foot and thus reduce the landing speed.

It is necessary not only to reduce the landing speed but also to reduce the length of run of the machine after touching the ground. This has been more or less successfully accomplished by the use of brakes on the main landing wheels and auxiliary wheels well ahead of the center of gravity to keep the machine from turning over. At the same time that we consider the advantage of low landing speeds to get into small fields, we should not forget that it is also necessary to leave these fields. It would be highly advantageous to develop machines which will gain their normal flying speed after a short run and have a high climb at low speeds of advance. In

Digitized by Google

getting out of small fields climb per distance and not climb per time is the important factor. As previously stated, the development of airfoils will improve this condition as well as that of low landing speed. Once we have secured this much-desired ability to get in and out of small fields, the safety and usefulness of the airplane from a commercial standpoint will be increased enormously. Not only will we be able to reach points that are not now available near cities, but we can fly over congested or mountainous districts with perfect safety.

Of next importance to safety is cost. There is no doubt in my mind that the future airplane can be greatly simplified and thus greatly reduced in initial cost, and at the same time be made sufficiently durable so that the cost of upkeep will be little more than that of an automobile. Most airplanes at the present time, whether they are manufactured in small or large quantities, are practically a hand-made product and this must be eliminated in the future. The concentration of efforts toward enormous climbs and speeds for military purposes has resulted in extremely complex structure, delicate workmanship and expensive materials. However, the military airplane has developed many new materials which will result in not only more efficient machines but great reduction of initial cost. The use of waterproof veneer is of utmost importance and if judiciously employed will do away with fully 50 per cent of the number of small and intricate parts. In the past little attention has been given to the interchangeability of parts, it having been the custom to design each part for the particular purpose for which it was desired without regard to its use for different purposes. Proper attention given to this matter would go far toward eliminating the manufacture of airplanes by hand and would reduce both the initial cost and the cost of upkeep.

One of the airplanes now doing very successful work, which has a range of 540 miles at 90 miles per hr. carrying a load in addition to pilot and passenger of 2000 lb., costs 20c. per ton-mile for fuel. Reducing this range to 270 miles and utilizing the reduction of the necessary fuel for the carrying of additional load, brings the cost of fuel to 13c. per ton-mile. It will, therefore, be seen that proximity of landing fields has much to do with the reduction in cost of the operation of an airplane.

Digitized by Google

Size and Type of Commercial Planes

As to the size of the future commercial airplane, it is my opinion that the machines most used will be those carrying from one to twelve passengers or corresponding loads of mail or express. But for certain purposes we may expect to see airplanes of a size far beyond our present dreams. However, machines beyond a capacity of twelve passengers become somewhat unwieldy and expensive of operation. Much has been written about the limit of the size of an airplane with relation to the so-called square-cube law, maintaining that increasing the linear dimensions of an airplane increases the surface by the square, whereas the weight increases by the cube. However, I believe it has been conclusively proved that this law does not hold true, and that it is perfectly feasible by unit structure and the added opportunities for reduction of head resistance, and improved structure, to increase the size of an airplane to practically any extent and increase the weight little if any more than in proportion to size. We cannot hope to compete in this respect with the dirigible in the case of which increase of size is highly advantageous, the percentage of structural weight decreasing and percentage of useful load increasing with the increase of size. Due to the lack of available landing fields, it is probable that the tendency toward increase in size of the airplane will be greater for water than for land use.

Durability has been of very little importance, but for commercial purposes the upkeep becomes an enormous item of cost. This is true not only of the airplane itself but also of the engine propelling it. Both the initial cost and the cost of upkeep are about equally divided between the engine and the airplane. The engine cost must be greatly reduced. In the most efficient weight-carrying airplanes of today with a loading of 20 lb. per hp. the structural weight of the airplane itself is about 30 per cent of the weight of the machine fully loaded and the weight of the engine is about 20 per cent of the total weight, leaving 50 per cent for fuel and useful load. For a range of 600 miles, the weight of the fuel is about 20 per cent, leaving about 30 per cent for useful load. Improvements in the airplane structure will greatly reduce the percentage of structural weight and will allow the use of heavier engines with corresponding reduction of cost. It is very doubtful whether the trend of engine design will be in this direction, as efforts will be concentrated

Digitized by Google

toward the increase of the percentage of useful load carried.

I have previously stated that we must not sacrifice high speed for low landing speeds. Likewise we must not sacrifice this high speed for reduction of engine cost. It seems that one of the greatest advances that could be made in engine design is the development of an engine that would maintain its horsepower at high altitudes. If the horsepower could be maintained at high altitudes, the speed of the airplane would be greatly increased thereby, and it would then be feasible not only to decrease the landing speed without sacrificing the high speed but the use of engines of lower horsepower would be possible. It is probable that the development of an engine of this type would demand a variable-pitch propeller to get the maximum speed at altitude. If such a propeller were used, it would not only increase the speed at altitude, but by reducing the pitch and allowing a corresponding increase in engine speed, the efficiency of the propeller would be increased at low speeds of advance so that the landing speed of the airplane would be greatly reduced.

As to the particular type of airplane to be used for commercial purposes, the tractor would seem to be most advantageous. Inasmuch as safety is of the greatest importance and most wrecks occur in landing, the pilot and passenger should be located well to the rear of the center of gravity, so that the heavier parts of the machine, such as engines, etc., will reach the ground first in case of accident. The two classes of accidents which are most common to the airplane are wrecks due to bad landings and nose dives resulting from engine stoppage in climbing out of a field when the altitude is not sufficient for the machine to recover.

It would also appear that multi-engined machines will not only add to the safety of the machine but also reduce the cost per ton-mile and by decreasing the liability of breakage thus reduce the cost of upkeep. You will probably assume that the use of multi-engines means an increase in the weight of the powerplant, but on investigation it will be found that the opportunities given for the reduction of the structural weight due to the distribution of loads are so great that the structural weight of the machine will be decreased in far greater proportion than the weight of the engines is increased.

For long flights the weight of fuel is a very large pro-

Digitized by Google

portion of the total weight of the machine, and as the journey progresses the fuel is reduced and the range may be greatly increased by throttling the engine. You are all aware of the fact that throttling an engine is a most inefficient manner of reducing horsepower. With the multi-engined machine it becomes perfectly feasible to cut out one or more engines as the case may be when the flight is partially completed, leaving the remaining ones operating at maximum efficiency and best economy.

A multi-engined machine is undoubtedly much safer, as we can assume that all of the engines will very seldom stop at once, and even though the remaining engine or engines are not sufficient to maintain constant altitude, the gliding angle will be enormously increased. For small passenger-carrying machines twin engines are extremely advantageous as with them it is possible to design a tractor type of airplane which will be perfectly clean and avoid the objectionable drifting back of oil into the pilot's face, always present in a single-engined tractor type. Maneuvering on the ground also becomes much easier, by throttling one engine or the other the machine can be maneuvered with the wind without a group of mechanics to assist the pilot.

I would like to point out that the greatest assistance that can be given the airplane engineer in the design of commercial airplanes is the development of engines. There are very few suitable engines in existence. As with the airplane itself, all attention for the past few years has been given to engines of very high horsepower and extremely light weight, with initial cost and cost of upkeep as purely secondary considerations. It is probable that some of the existing airplane engines, if built in enormous quantities, could be produced at a reasonable cost, but the production of commercial airplanes is, at the present time, somewhat limited and the growth of the industry must necessarily be gradual. It would, therefore, seem that the production of existing type of engines will not be sufficiently great to get the cost down to a reasonable basis. Engines of medium horsepower would be highly advantageous for smaller types of commercial planes, and a very satisfactory sportsman's machine of the twin-engined type with units of 60 or 70 hp. would be a desirable product, and it should be possible to produce such engines at a comparatively low cost. For this type of machine the air-cooled type of engine would be particularly de-

Digitized by Google

sirable inasmuch as the engine can be of comparatively small size and small bore and can be exposed in a manner which would not be practicable in a single-engined type. All air-cooled engines which have previously been brought out have been of a type in which efforts have been made to reduce the weight to an extent far beyond that of the water-cooled type. I believe that an air-cooled engine of medium horsepower, weighing the equivalent of a fully equipped water-cooled engine including radiator and water, would make an efficient powerplant and one which could be produced at very low cost.

THE CASE FOR THE AIRSHIP

By Ladislas d'Orcy[1]

On the basis that it is impossible to state the case for either the airship or the heavier-than-air machine without some comparison of the two, the author discusses relatively features, points of merit or superiority and the fields of usefulness thus far disclosed in the rapid development of the craft. Progress since 1914 is outlined, a brief history to date is included and the way prepared for consideration of the possibilities of long-distance flight.

A comparison of the features given emphasizes strongly the point that the airplane is mainly a high-speed, short-distance carrier, while the large rigid airship is essentially a medium-speed long-distance carrier. Each type has a distinct sphere of activity; the airship in transcontinental, transoceanic traffic; the airplane in feeding the terminals of the airship with passengers and, possibly, certain kinds of freight. The salient features of the airship are great endurance, large cargo capacity, ability to remain aloft in bad weather, and space and comfort for passengers.

The secondary position of the United States in the rank of development is stated frankly. The non-inflammable lifting gas, of which we have an almost unlimited supply, should place us in the forefront for speedy, long-distance transport.

[1]Associate editor, *Aviation and Aeronautical Engineering*, New York City.

Digitized by Google

In stating the case for the airship it is really impossible to give the subject an adequate defense without entering into a controversial discussion with the advocates of heavier-than-air machines. Although the features of airships and airplanes are so widely different that each type of aircraft promises to cover quite different fields of usefulness, the impression prevails at large that the airplane will eventually displace the airship, be it for military or commercial purposes.

This wholly erroneous impression does not take into account the extraordinary development that has taken place in airship construction in the last four years, which has been kept even more secret than airplane progress.

Progress Made Since 1914

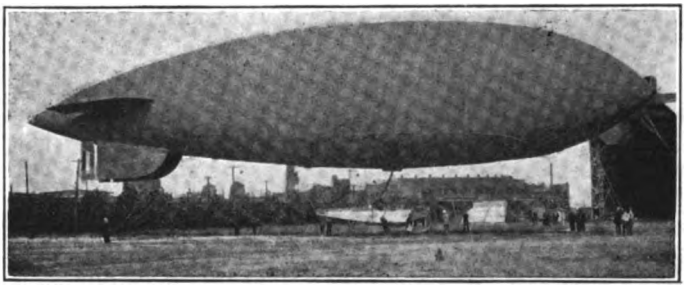
Before discussing the more general problems of lighter-than-air craft with respect to their possible use in times of peace and war, some figures will be given to show at once the great progress realized in this domain during the Great War. As Germany was, at the signing of the armistice, still leading in airship construction, though closely followed by Great Britain, two German naval Zeppelins, the L3 and the L71, will be taken as representative of the stage of progress in 1914 and in 1918.

From the L3 to the L71 the gross, or total, lift has increased from 30 to 66.64 tons; the disposable lift, or useful load, from 8.5 to 38.84 tons; the efficiency ratio, that is, the ratio of disposable lift to gross lift, from 27.3 to 58.3 per cent; the total horsepower, from 800 to 2100; the full speed at 10,000 ft., from 50 to 77.6 miles per hr.; the cruising endurance, at 45 miles per hr., from 20 to 177½ hr.; and the static ceiling, that is, the altitude that can be reached by purely static means, from 6000 to 21,000 ft.

The most impressive of the above figures are, to my mind, the ones showing the increase in efficiency ratio, which has about doubled with the twofold increase in capacity of the Zeppelin, for this well illustrates the one very important feature of lighter-than-air craft which confers upon them a superiority over heavier-than-air craft, namely, that an increase in the size of airships gives greatly improved efficiency. In airplanes, on the

Digitized by Google

contrary, efficiency not only remains stationary with the sizes now reached, but is even likely to decrease with further increases in size. At the present time the old all-round British airplane, the DH-10a, with two 400-hp. Liberty engines, has an efficiency ratio of 36.1 per cent. This machine has a high speed, at 10,000 ft., of 125 miles per hr., a cruising endurance of 14 hr., a ceiling of 19,000 ft., and a useful load of 1.45 tons. As against this performance the best all-round airplane of 1914, the two-seater 80-hp. Avro, with an endurance of 4 hr., showed an efficiency ratio of 36.3 per cent, so that there has actually occurred a slight loss of efficiency, and it

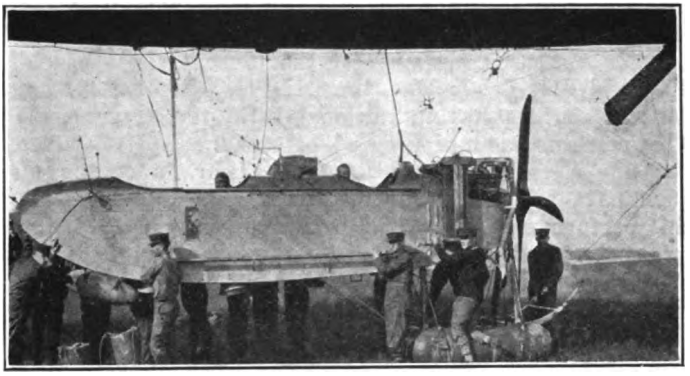


TRACTOR "BLIMP," BUILT BY THE GOODRICH CO. FOR THE U. S. NAVY AND EQUIPPED WITH ONE CURTISS OXX 100-HP. ENGINE

can be said that this would have been greater but for considerable improvement in design.

The reason why in an airship the efficiency ratio is improved with an increase in size, whereas in the airplane it remains at best stationary, is due to the fact that the airship derives its lift from volume, while the airplane derives its lift from area. Now, in either case what may be termed the unit of lift, cubic feet of volume or square feet of area, exerts only a definite lifting effect; in the airship this is determined by the specific gravity of hydrogen or helium, and is therefore immovable, whereas in the airplane it depends upon progress in design, and is thus still open to improvement. This fact may, in a certain measure, work out in favor of the airplane, but there are other factors which actually limit the practicable size of heavier-than-air craft.

Digitized by Google



CAR OF THE GOODYEAR PUSHER "BLIMP"

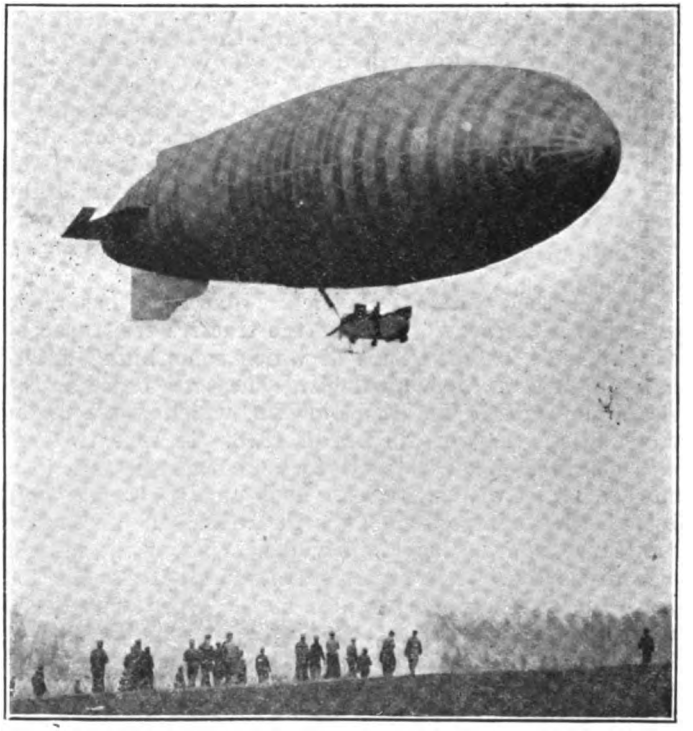
One of these is that while the lift of an airplane theoretically varies with the square of linear dimensions, the weight of the wing structure per unit of area does not remain stationary with an increase of wing area, but increases, because the larger wing structure must be made proportionally strong. Consequently, a size is eventually reached where every additional square foot of surface weighs as much as it can lift, so that beyond this size there will occur a marked reduction in efficiency.

Now we know that the strength of similar structures is inversely proportional to their linear dimensions. This rule applies equally to airships and airplanes, but while the lift varies as the cube of dimensions in lighter-than-air craft, and as the square in heavier-than-air craft, an increase in lift is attained in airships with much less increase of dimensions than in airplanes. For instance, if we double the span, and, to retain the same aspect ratio, the chord of a given airplane, the lift will increase four times, while theoretically the weight will have to be eight times as great if we want to obtain the same structural strength. But in an airship, when we increase the lift four times, we increase the length of the structure only by the cube root of four, that is, approximately one and a half times, so that the weight of the structure will be only four times greater for the same proportionate strength, which is to say that the weight of an airship is, for the same structural strength, directly proportional to the total lift.

Digitized by Google

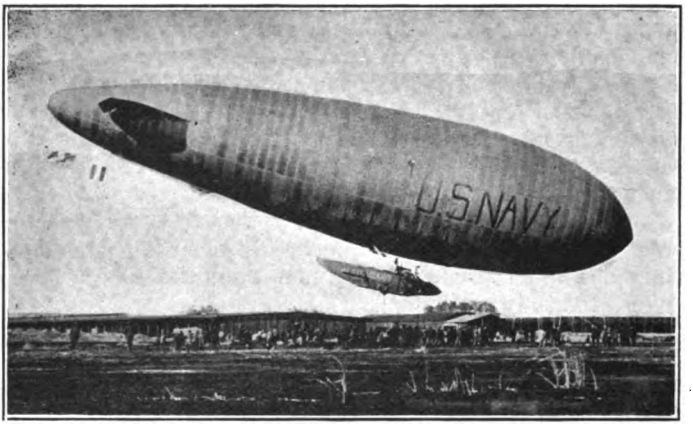
Now, it is true that, as heavier-than-air advocates contend, the law of geometrical similitude is not strictly applicable when aircraft are increased in size, because more suitable materials become available for constructing large machines, or else, available materials can be used in a more advantageous form. However, this rule applies to lighter-than-air craft as well as to heavier-than-air types; and it must be conceded that even with allowance for improved efficiency due to more suitable materials of construction, the weight of an airplane *does* increase in a greater proportion than the lift, at best like 3 to 2, always provided the same structural strength is desired.

Another technical advantage afforded by the airship



PUSHER "BLIMP," BUILT BY THE GOODYEAR CO. FOR THE U. S. NAVY, EQUIPPED WITH ONE THOMAS 150-HP. ENGINE

Digitized by Google



COASTAL AIRSHIP OF THE U. S. NAVY, BUILT BY THE GOODYEAR CO., AND DRIVEN BY TWO 150-HP. TWIN-SCREW HISPANO-SUIZA ENGINES

is that the so-called coefficient of tractive resistance, that is, the ratio of the weight of machinery to total lift, obviously decreases with an increase of size, because the lift varies as the cube of the linear dimensions, while the resistance of the air and the brake horsepower vary as the square of the dimensions, all other things being equal.

The British National Physical Laboratory has made an exhaustive investigation of the tractive resistance of airship hulls, as the result of which some highly interesting figures are now available. These are based on the streamline hull of the Zeppelin L33, which was brought down in England in the fall of 1916. It appears from these figures that the tractive resistance decreases in a marked degree with an increase in size and a *proportionate* increase in horsepower. Thus the coefficient of tractive resistance of a 60-ton rigid, which is about the largest size in existence, is 1.9 per cent at 45 miles per hr., 3.8 per cent at 60 miles per hr., and 7.7 per cent at 80 miles per hr., as against that of a 300-ton rigid, which is 0.9 per cent at 45 miles per hr., 1.8 per cent at 60 miles per hr., and 3.6 per cent at 80 miles per hr. In other words, a 300-ton rigid can fly more economically at 80 miles per hr. than a 60-ton rigid can at 60 miles per hr.

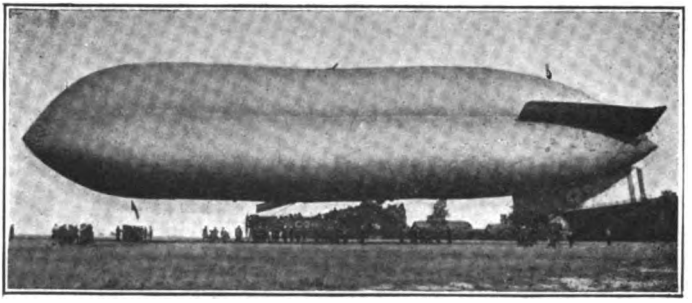
This explains why the performance of the latest Zep-

Digitized by Google

pelins, which have almost trebled in size since 1914, has so marvelously improved. One such performance, which has recently been made public by the British Air Ministry and cannot, therefore, be taken for enemy propaganda, fittingly illustrates the tremendous possibilities of the large rigid airship in long distance aerial transport. In the fall of 1917 the German Admiralty ordered one of its airships to undertake a relief expedition in behalf of the German force that was surrounded by the Allies in East Africa. Accordingly the naval Zeppelin L59, after having been loaded up with some 20 tons of munitions and stores, left Jamboli, Bulgaria, at 8:35 a. m., Nov. 21, heading for East Africa. The airship proceeded as far as Khartum, Egypt, which she reached in the early morning of Nov. 23, when she received a radio message from the German Admiralty, ordering her to return, as the force to be relieved was reported to have surrendered. The L59 thereupon put back to Jamboli, where she arrived without any untoward incident on the morning of Nov. 25, having covered in the course of her 4-day cruise a distance estimated at 4500 statute miles or 7300 km.

Possibilities of Long Distance Flight

As the shortest distance between America and Europe, from St. John's, N. F., to the southwest coast of Ireland, is somewhat less than 2000 English miles, it is obvious that an airship of the L59 class could, with the crew of twenty-two and some 20 tons of cargo she carried



British Coastal Airship, Astra-Torrès Type, with One 110-Hp. Berliot Engine Forward, One 260-Hp. Fiat Engine Aft, One Tractor and One Pusher Airscrew

Digitized by Google

on that memorable cruise, easily cross the Atlantic both ways without even refuelling. In view of such a voyage the best airplane performance naturally dwarfs to a considerable degree; nor is there anything extraordinary in the report that the Zeppelin Co. is engaged in building an airship of 115 gross lift tons and 2400 hp., which will carry 100 passengers, 45 tons of cargo, and 30 tons of fuel and provisions across the Atlantic, of course if Marshal Foch will permit it.

But it does not seem likely that we shall have to wait for a German airship to open up the aerial route across the Atlantic, for some recent information at hand tends to show that a British rigid airship will attempt this venture as soon as favorable weather sets in, that is, sometime in the coming spring.

I now propose to answer some of the principal objecttions which are made against the use of airships in passenger transportation, for I do not think anyone familiar with the subject can deny their great potentiality as a military weapon since American chemists have successfully overcome the problem of producing a non-inflammable lifting gas, helium, in large quantities and at a comparatively low cost. One of these is that the comparatively low speed of airships makes these craft less independent of adverse winds, and, therefore, less reliable in operation on a schedule than the airplane. Airships have not yet exceeded a speed of 80 miles per hr., whereas airplanes have made speeds of over 150 miles per hr., from which the inference is naturally drawn that heavier-than-air craft will prove much more reliable and advantageous as time-savers in aerial transport than lighter-than-air craft. Arguments of this sort are, however, highly misleading, because speed alone cannot be considered the sole criterion of commercial utility; in considering aircraft for the purpose of transporting passengers and freight the element of speed must be jointly examined with the load carried and the cruising radius.

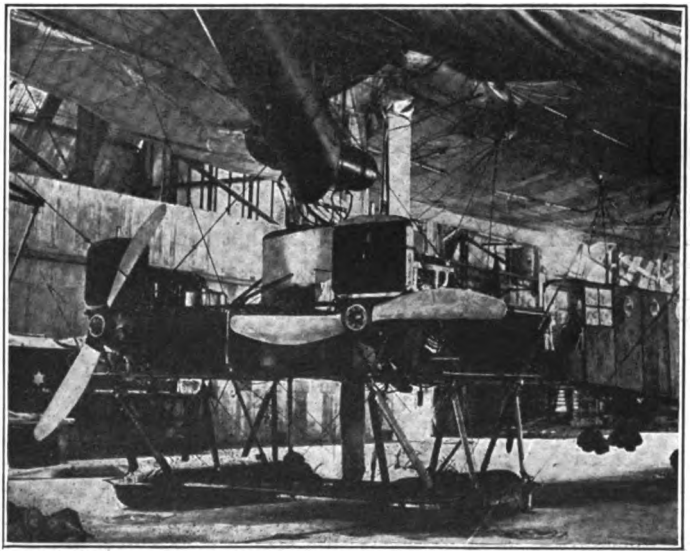
Referring again to the figures given before, it appears that the best existing all-round airplane, the DH-10a, can fly at a speed of 125 miles per hr. for 14 hr., that is, in still air, over a distance of 1750 miles; while the best existing airship, the L71, can fly at a cruising speed of 45 miles per hr. for 177½ hr., or 7½ days, that is, in still air, over a distance of 7987.5 miles, or roughly 8000 miles.

Digitized by Google

A comparison of these figures strongly emphasizes the point that the airplane is mainly a high-speed short distance carrier, while the large, rigid airship is essentially a medium-speed long-distance carrier; either type of aircraft has therefore its well appointed sphere of activity in aerial navigation. Airships can be employed to best advantage on routes exceeding 1000 miles in length, while airplanes will prove useful on trips of shorter distances, where the time employed in putting off and taking on passengers and in refuelling would curtail the saving of time effected by aerial travel.

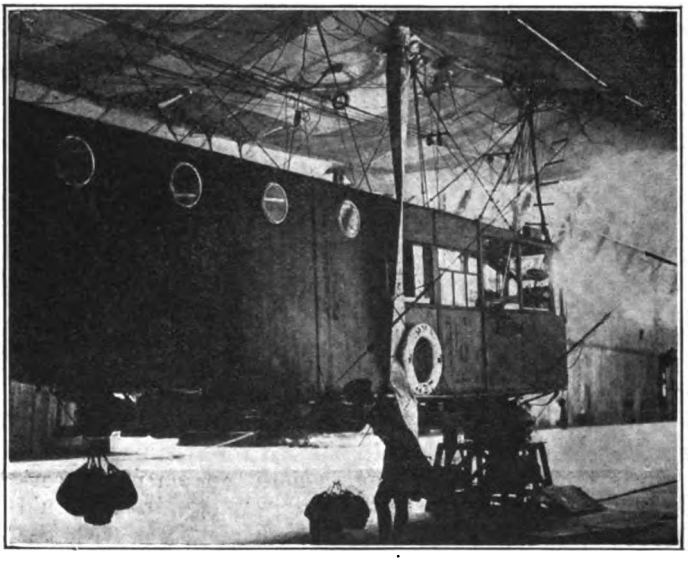
Fields of Airplanes and Airships

It has therefore been suggested that airships should mainly be employed in transcontinental and transoceanic traffic, while airplanes could be used for feeding the airship terminals with passengers hailing from places several hundred miles distant. In this way the airship would compete with the steamship, and the airplane with the



After Portion of the Car, and Engine Installation of the NS7

Digitized by Google



FORWARD PORTION OF THE CAR OF THE BRITISH AIRSHIP NS7 (NORTH SEA CLASS).
Note Bombs Carried under the Floor

railroad train; the saving of time would in either case amount to at least 50 per cent.

The great endurance and cargo capacity of airships are not, however, the only features that make them particularly desirable for the long-distance transportation of passengers and freight. One of the important points in favor of lighter-than-air craft is that they afford a decidedly greater element of safety than heavier-than-air craft, because an airship can stay aloft regardless of engine failure, whereas a stoppage of the airplane's power-plant necessitates an immediate descent in gliding flight. Now, there is no inherent danger in such a descent, provided suitable landing grounds are available at given distances; but until a chain of numerous landing stations is created along the lanes of future aerial travel, some risk will be involved in public transportation by airplane, especially over wooded and marshy country and over the ocean. It is in transoceanic traffic that the greatest future of the airship seems to lie, because there compe-

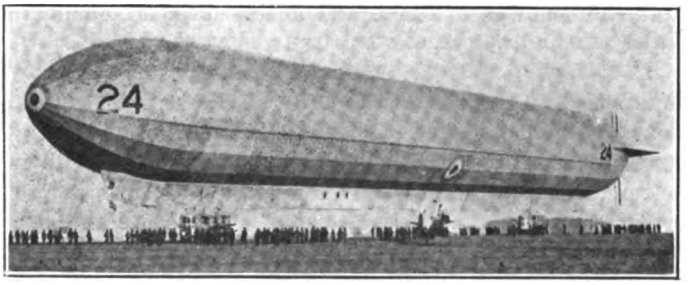
Digitized by Google

tition with the existing means of transport will be much easier owing to the low speed of steamships, if compared to railroad trains, and because alighting in a stiff gale is not at all pleasant to visualize.

Still another factor which seems to favor lighter-than-air craft in public transportation over long distances is that the requirements of comfort can be attained much easier than on heavier-than-air craft. First of all, weight is, comparatively speaking, a matter of minor importance on airships because of their great buoyancy; and secondly, the large size of the hull affords better opportunities for fitting not only spacious staterooms, lounges, etc., but of fitting them so that they will be sufficiently removed from the engines and airscrews to actually suppress the resulting vibration and noise. Furthermore, a promenade deck of several hundred feet in length can be provided on top of the hull. All these may seem minor matters, but they should not be overlooked, for the mere saving of time will not attract a large section of the traveling public to aerial transportation unless a sufficient amount of comfort be afforded as well.

Position of United States on Development

The question now arises, since the value of airships for commercial purposes seems to have been sufficiently outlined, where does this country stand in the development of lighter-than-air craft? To date only small size non-rigid airships have been built in the United States, and this exclusively for the needs of the Navy. These ves-



The British Rigid Airship R24, a Vessel of Pre-War Zeppelin Type, Notable for Its External Keel

Digitized by Google

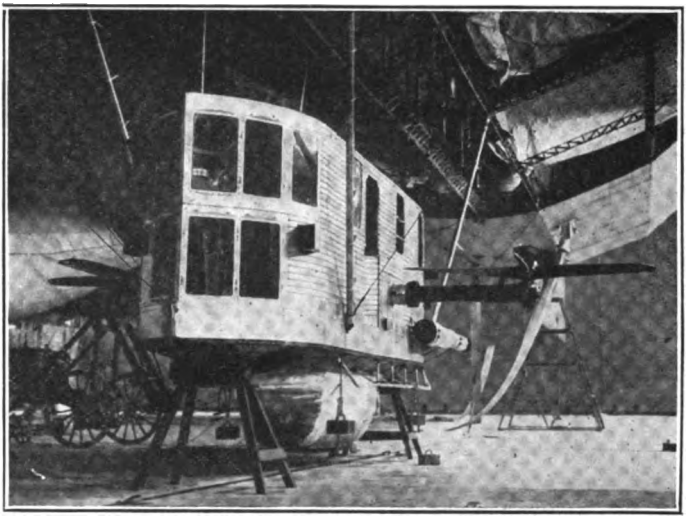
sels subdivide into two classes, the so-called "Blimps," or submarine scouts, and the Coastal, or C-class ships; the former have a capacity of about 100,000 cu. ft. and a single engine of 100 to 150 hp., driving a tractor or pusher screw, while the latter displace about 200,000 cu. ft. and are driven by two 150-hp. engines and twin screws. Although both types are adaptations of British designs, various improvements have been introduced in these ships by American manufacturers, particularly in the development of the larger type, which can be considered as a distinctly American product. This is especially noticeable in the rigging of the car to the hull, which is of the finger patch system on the American Coastals, whereas in the British C-class vessels the car is rigged to an internal "rope girder" which is kept in tension by the tautness of the hull. This rope girder is of triangular form in transverse cross-section, the apices of the triangles being secured to the intersection lines of the three-lobed hull.

A larger type of non-rigid airship, which the British have developed for scout work with the fleet, is the North Sea class. These ships have a capacity of 360,000 cu. ft., two 260-hp. engines, and a full-speed endurance, at 57.5 miles per hr., of 20 hr.; they carry a crew of ten. So far no corresponding type has been produced in this country, and the same remark applies to the large rigid ships Great Britain has been developing with great steadiness since the war. One of these vessels, the R33, which is reported to be awaiting the completion of certain arrangements prior to attempting to cross the Atlantic, has a capacity of 2,000,000 cu. ft., five engines giving a total horsepower of 1250, and a full speed of about 70 miles per hr.; her crew numbers twenty.

In a report recently made to Secretary of the Navy Daniels on the aeronautical needs of the Navy Admiral Mayo pointed out that the latest British rigids possess an endurance of well over 200 hr., which would give them a range "safely across the Atlantic and return in any weather except the worst storms." Therefore the construction of four rigids, each to cost $1,500,000, was recommended and due provision has since been made for this purpose in the Naval Appropriation Bill.

While the Navy has, since the war, been in the van of lighter-than-air development, it would seem desirable

Digitized by Google



THE AFTER CAR OF THE R29, WITH ITS SWIVEL-MOUNTED AIRSCREWS

that American engineering firms also pay some attention to this phase of aeronautical progress, particularly as regards the construction of rigid airships, that a repetition of the aerial unpreparedness which characterized this country two years ago may be prevented in case of future emergencies. Since a non-inflammable lifting gas has become available, of which the United States possesses an almost unlimited supply, the airship promises to play in future conflicts a much more important rôle than in the Great War, great as this has been. But even if future wars should be made impossible, the United States will need a large fleet of rigids for the demands of fast long-distance transport, unless, of course, this country prefers to see this traffic go to airships flying foreign flags.

Digitized by Google

AIRCRAFT RADIATORS

By Archibald Black[1]

THIS paper describes the various types of radiator installations in use. Tabulated data on several makes of radiation and on successful airplane radiator installations are given. A brief review of laboratory tests is made and the features to be considered in design and manufacture are discussed. The author concludes by cautioning engineers against attempting to base new designs entirely upon experimental data, without comparing the tentative design with existing successful installations.

The earliest radiator used on a successful airplane for the cooling of an internal-combustion engine was the flat-tube type installed on early Wright machines. This radiator, which was very much the same as the one used on the Wright Model B, consisted of flat tubes set vertically between the wings of the machine, as is clearly shown in the illustration.

Closely following the Wrights, the Aerial Experiment Association, consisting of Glenn H. Curtiss, Dr. Graham Bell, J. A. D. McCurdy and others, built the "June Bug," a small biplane, using a honeycomb radiator mounted in front of and slightly higher than the engine, in a manner only slightly different from some of our present practice. An early U. S. Navy plane with an installation of this type is shown in one of the illustrations.

Over in France Le Vavasseur installed on the Antoinette monoplane a radiator consisting of a series of long tubes running fore and aft and mounted on the side of the fuselage.

The three types just described are so thoroughly typical of the various early installations that it appears unnecessary to refer to any others, and the remainder of this paper will therefore be confined to existing practice.

Modern Radiator Installations

In general, six types of mountings for aircraft radiators are used today and a brief description with illustrations of typical cases follows.

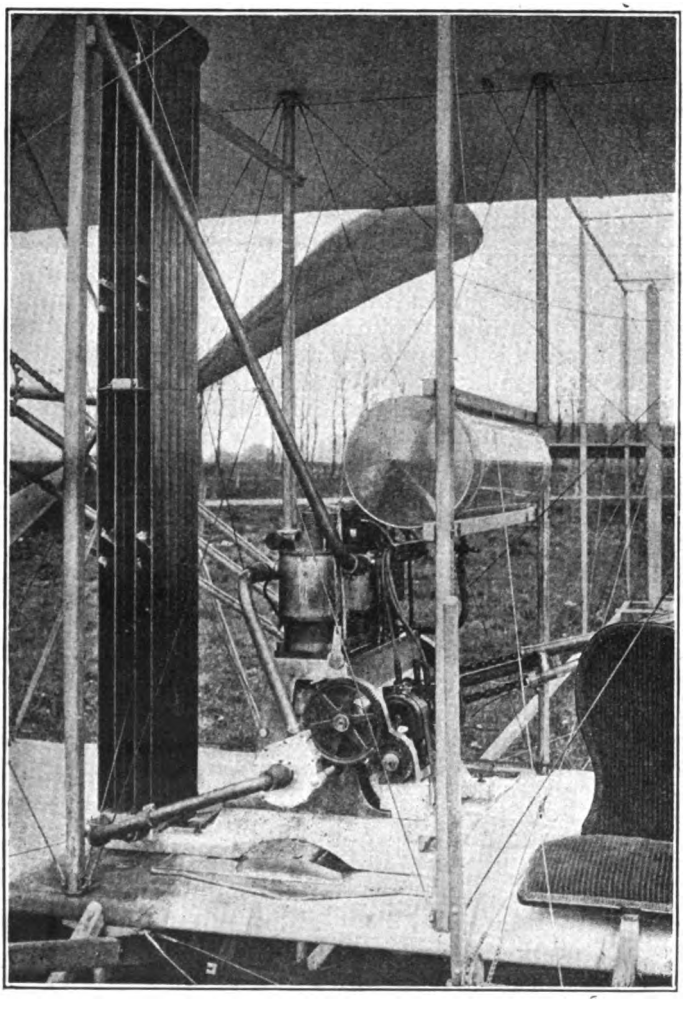
---

[1]Aeronautical mechanical engineer, Navy Department, Washington.

Digitized by Google

Type 1 The installation of the radiator in front of the engine and on the nose of the airplane fuselage is one of the commonest of present methods of disposing of this question. The radiator is of the honeycomb type and part of the radiation is cut away to permit the crankcase extension to project through.

The Christofferson tractor, L-W-F model V, and also



RADIATOR INSTALLATION ON WRIGHT MODEL B

Digitized by Google

the Curtiss models JN-4 and R-4 are typical examples of this mounting and a similar radiator is used on the LWF model V-1. In addition to these radiators, there is a fuselage nose radiator in which the radiation has been bent to a curve.

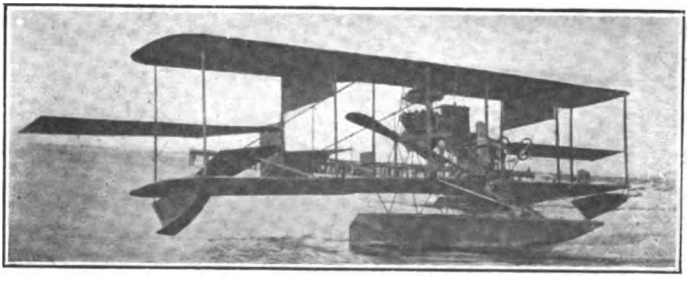
Type 2 An installation used largely on pusher-type flying boats places the radiator in front of the engine. The Curtiss model HS-2-L is an excellent example of this type.

Type 3 An installation much used on German airplanes and also used, but not extensively, in this country, is the mounting of the radiator on or just below the nose of the upper wing. The Sturtevant and the L-W-F model G-2 radiators are examples of American applications. It should be noted that the upper water pocket of each of these radiators forms the nose of the upper wing, thus eliminating the air resistance of this pocket. This improvement was introduced by the Sturtevant Aeroplane Co.

Type 4 Another installation popular in this country at one time, but discarded of late, calls for the placing of a tall, narrow, honeycomb radiator above the engine and extending to and often above the upper wing. The Wright-Martin model R and the Standard model J are good examples of this.

Type 5 Another method not now in use was to place the radiators on each side of the fuselage. The Aeromarine training model is an excellent example of this type. The Standard installation is a compromise between this and the previous method.

Type 6 The latest development in radiator installation, introduced in the last two years by the German Albatross designers, consists of setting the radiator in



EARLY U. S. NAVAL AIRPLANE SHOWING RADIATOR INSTALLATION

Digitized by Google

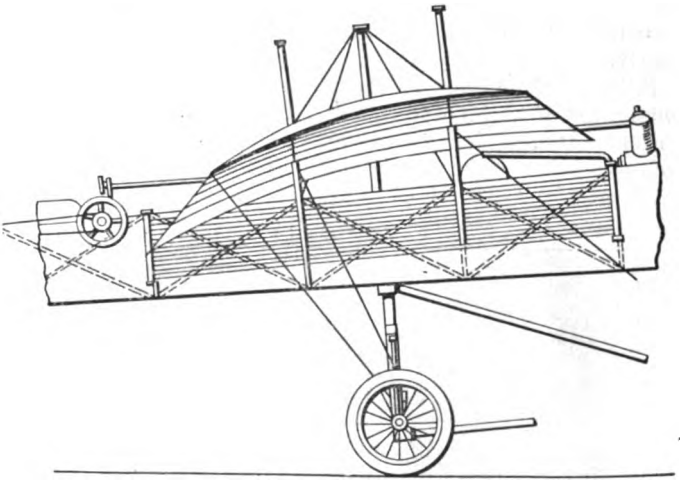
Digitized by Google

the
of
L W
a fi
ben
T
fly i:
The
typ
T
plan
try,
nos
moc
tion
each
thus
imp
plan
T
at o
a ta
exte
Wri.
gooc
T:
the
mar
type
twee
T
tion,
Alba

EAR

Digitized by Google

the upper wing and in some cases making it conform to the wing curve. This installation in my opinion may become the ultimate solution of the radiator problem, as it has much to commend it. It sometimes introduces structural difficulties through interference with the in-



RADIATOR USED ON THE ANTOINETTE MONOPLANE

ternal wing wiring, but these difficulties are by no means insurmountable.

The Albatross, a tubular type, and the Le Pere, a flat plate type of radiator, will be described in detail later in this paper.

Some wing-curve radiators have been constructed out of standard honeycomb radiation. The L-W-F model G-2 experimental radiator is a good example. While this radiator was a trifle too small, it proved that honeycomb radiators could be used successfully in this manner. The Garford Co., Elyria, Ohio, and Capt. V. E. Martin have also tried some similar experiments.

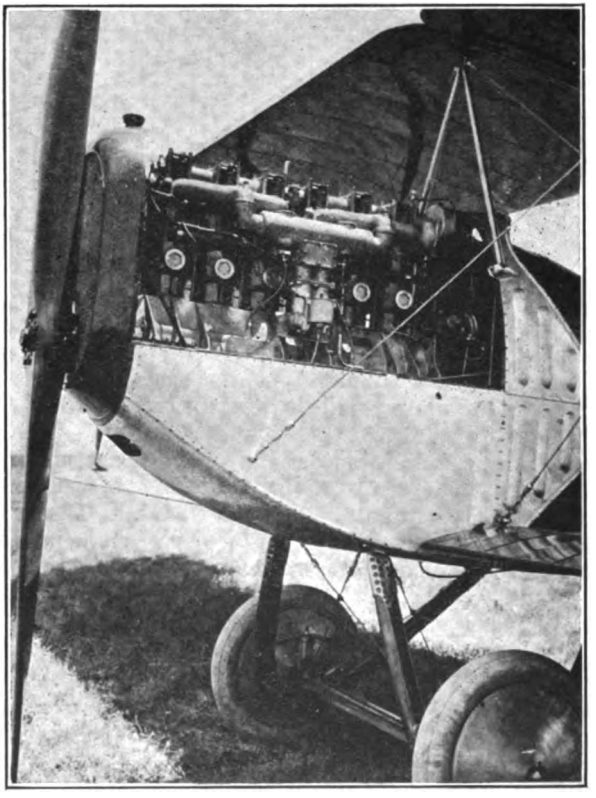
MODERN TYPES OF RADIATION

Honeycomb The honeycomb type of radiation is at present the most used, largely on account of its adaptability and of the fact that it is well suited to large production at moderate cost. It is made in a considerable number of forms, by many American manufacturers. The Gallay radiation is made by a British firm. The

Digitized by Google

Flexo radiation is more or less flexible. The Harrison tubular, Multitube and similar forms are built up by soldering small tubes together. This latter type of radiation has been standardized by the British because of its manufacturing advantages and performance. Table 1 gives the characteristics of several American types of honeycomb radiation. The sections referred to are drawn slightly out of proportion to show the water spaces clearly.

Tubular The use of the tubular type of radiation, consisting of water tubes with radiating fins, has been largely confined to installations where the radiator is mounted on the side of the body. This type of radiation



FUSELAGE NOSE RADIATOR ON CHRISTOFFERSON TRACTOR

Digitized by Google

is not used extensively in aircraft at present, for reasons which will be stated later. Table 2 gives the characteristics of the Rome-Turney, an American type of tubular radiation.

Albatross The following data obtained from the radiator of a captured Albatross machine may be of interest. The radiator consisted of 650 flattened copper tubes running laterally across an opening in the wing. Water entering the upper part of the right-hand water pocket flowed through the upper tubes to the left-hand water pocket and returned through the lower tubes to the lower part of the right-hand pocket. The top and bottom of water pockets were designed to set flush with the wing surfaces, and the radiator was supported by cast brackets, riveted to the water pockets, which rested on the wing beams. As stated, the tubes were flat and the flat sides were set at an angle of about 40 deg.

TABLE 2—CHARACTERISTICS OF A TYPICAL AMERICAN MAKE OF TUBULAR RADIATION

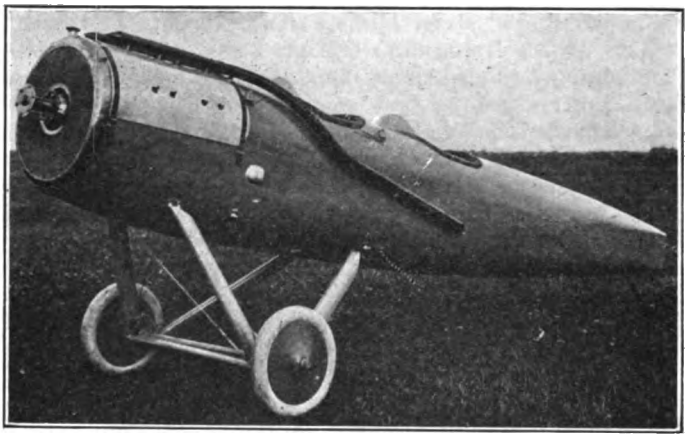
Manufacturer	Diameter of Tube, In.	Thickness of Tube Wall, In.	Width of Ribbon, In.	Thickness of Ribbon, In.	Overall Diameter of Complete Tube, In.	Radiating Surface per Foot of Complete Tube, Sq. In.	Complete Tube Empty, Lb. per Ft.	Water per Ft. of Tube, Lb.
Rome-Turney Radiator Co., Rome, N. Y.		0.020	3/16	0.010	3/4	52.23	0.174	0.038
	3/8	0.020			7/8	73.03	0.219	0.038
		0.026	1/4		7/8	73.03	0.243	0.035
	1/2	0.022		0.012	1	89.54	0.286	0.070
		0.028			1	89.54	0.317	0.067
	3/4	0.041	3/8		1 1/2	144.77	0.641	0.152

to the wing chord. An expansion tank was provided at the front.

The weight of the radiator was 27½ lb. and it held 2½ gal. of water. It was used in conjunction with the Mercedes 160-b.hp. engine and a ¼-in. connection was made between the rear cylinder and the radiator expansion tank to prevent a steam pocket when diving, the main water connection being made to the front of the engine.

The areas of the radiator, probably the lowest per brake horsepower on record, worked out as follows, based on 160 b.hp.:

Digitized by Google



FUSELAGE NOSE RADIATOR ON THE L-W-F MODEL V AIRPLANE

Area of tubes .....45.65 sq. ft. = 0.285 sq. ft. per b.hp. of engine
Area of exposed casing.. 2.965 sq. ft. = 0.0185 sq. ft. per b.hp. of engine

Total area .....48.615 sq. ft. = 0.3035 sq. ft. per b.hp. of engine

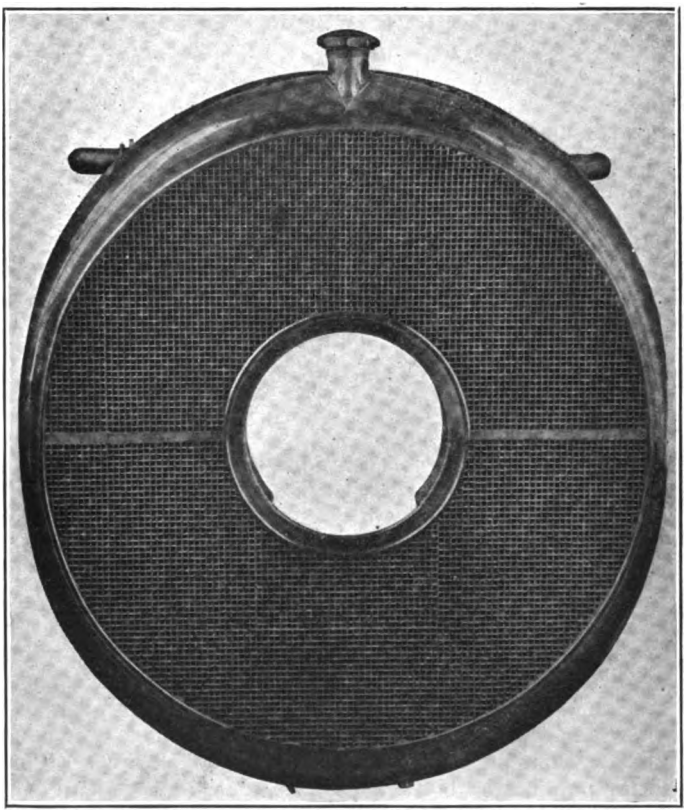
Plate The plate type of radiation, such as is used in the Le Pere radiator, consists of hollow flat plates through which the water circulates, while the air passes between them. In general it is made up of a series of these hollow plates set parallel, on edge, and spaced about 9/32 in. center to center. The plates are connected to distributing and collecting headers and are built up out of two flat and parallel sheets of copper separated by a central corrugated copper sheet. The process of manufacture, which is very ingenious, is as follows: The two flat and the center corrugated plates are clamped together with sheets of solder foil between the copper sheets. The temperature is then raised to above the melting point of the solder and the foil fuses, fastening the three plates together. The completed plates are then assembled with the collecting and distributing pockets. The central corrugated sheet makes the plates sufficiently rigid to eliminate the necessity for external bracing. This construction is a French invention. Data on some radiators of this type are given in Table 3.

Digitized by Google

Although this type of radiation has been used in this country only in the Le Pere and U.S.D.-9 radiators, both of which are set into the upper wing, it is also well adapted to other methods, such as mounting on the side of the body, or below the upper wing, etc. It is a very efficient type.

Theory

In his several papers (references Nos. 5, 6, 7 and 8—see list appended to this paper) F. W. Lanchester, the English engineer, has developed the theory of cooling cylinders of internal-combustion engines with the thoroughness which has characterized his many contributions to engineering knowledge. His discussions,



Radiator Used on the L-W-F Model V-1 Airplane

Digitized by Google

it might be mentioned, include direct radiation, as is used in the air-cooled engine, as well as indirect or water cooling.

A shorter discussion of radiator theory will be found in the article, "Notes on Radiators for Airplanes," by Lieut.-Commander J. C. Hunsaker, U. S. N. (reference No. 2). This paper, although written early in 1916, is very complete and contains some very interesting matter. Among other things he discusses the possibility of using a steam cooling system and shows that from the point of view of size of radiator it would have some advantages. Against this must be considered the fact that an engine operating at the high temperature required would most probably show a slight decrease in horsepower, and also that the use of a steam cooling system would greatly increase the danger of faulty circulation. It would be necessary to construct a radiator capable of withstanding considerable internal pressure in case of a rapid rise in temperature and consequently in pressure.

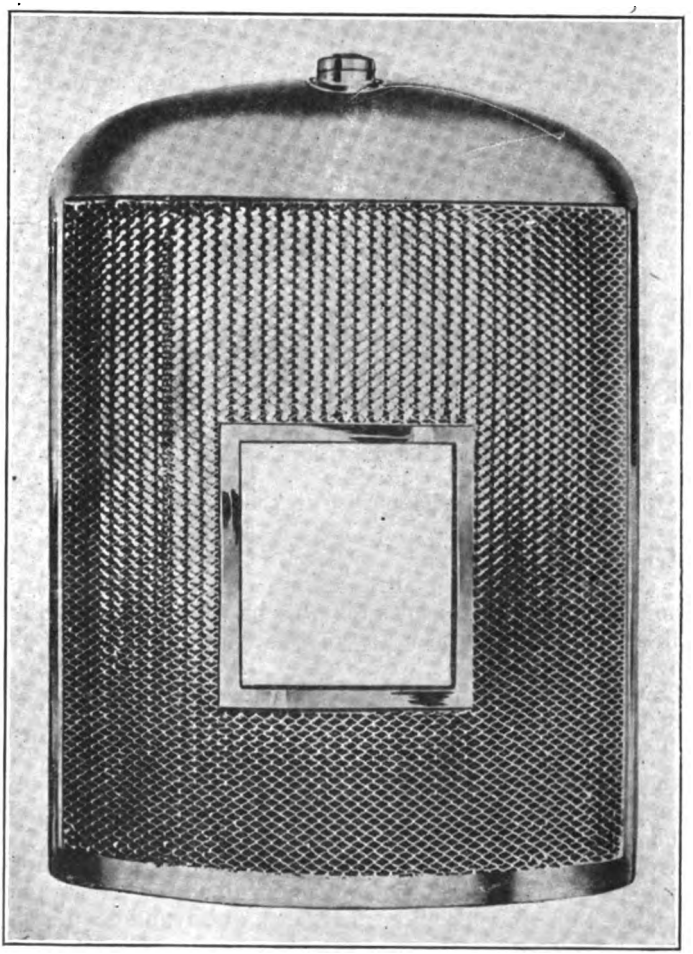
Table 3 gives tabulated results of the performance of a number of radically different installations of airplane radiators. It has not been possible to obtain complete data on each installation, but as much as could be obtained has been given. A few of the cases are a little out of date, as the tabulation was begun about three years ago. Where the data are not considered reliable this has been noted.

Section Technique Aeronautique Tests

The French Section Technique Aeronautique made in 1917 a very extensive series of laboratory tests on aircraft radiators, the results of which are given in their various reports. Unfortunately, owing to the confidential nature and source of these data, it is not permissible to include in this paper anything more than some very general comments. Copies of the reports cited, however, are in possession of both Navy and Army, and accessible to those connected with these Government departments, and the June, 1918, issue of the publication popularly known as the *McCook Field Bulletin* contains a very complete *résumé* of the reports (reference No. 12). This latter publication is available to the engineers of all contractors engaged on U. S. Government aircraft work and they are referred to it for the details of tests.

Digitized by Google

The tests included almost every type of honeycomb and some types of tubular and plate radiators. All of the tubular radiators offered more head resistance than the other types, some ten times as much, without a corresponding increase in radiation, although the highest dissipation of heat per unit area was shown by this type. The addition of fins to the tubes greatly increased the radiation with only a slight increase in head resistance.



FUSELAGE NOSE TYPE OF RADIATOR MADE OF FLEXO RADIATION IN WHICH THE HONEYCOMB IS BENT TO A CURVE

Digitized by Google

This increased dissipation, however, did not by any means offset the disadvantage of the high resistance and weight of this type, and tubular radiators can therefore be considered unsuitable for use in aircraft.

Among the radiators showing the best all-around performance, based on the horsepower required to carry the radiator and to overcome its resistance at 90 miles per hr., for a given water flow, temperature difference and heat dissipation, were the following, in the order of their merit:

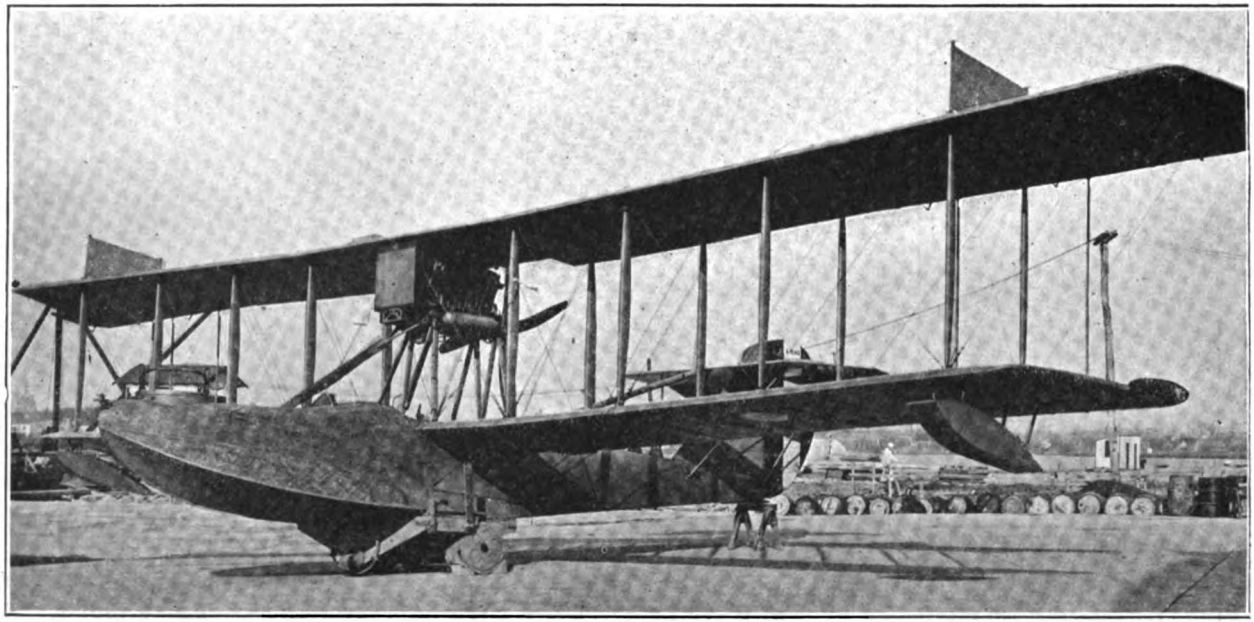
(1) Honeycomb radiator with air cells 0.42 in. by 0.42 in. by 3.55 in. deep
(2) Honeycomb radiator with air cells 0.441 in. hexagon by 6.3 in. deep
(3) Honeycomb radiator with odd-shaped air cells 3.95 in. deep
(4) Honeycomb radiator with air cells 0.441 in. hexagon by 3.95 in. deep
(5) Plate type radiator constructed with plates similar to those used in the Le Pere radiator: air space, 6.5 in. by 0.354 in. by 23.6 in. deep
(6) (*a*) Honeycomb radiator with air cells 0.315 in. by 3.95 in. deep. (*b*) Plate type, the plates being wavy, water tubes, air space 11.8 in. by 0.71 in. by 15.8 in. deep
(7) Honeycomb radiator with air cells 0.354 in. by 0.354 in. by 8.65 in. deep
(8) Honeycomb radiator with air cells 0.275 in. hexagon by 3.95 in. deep

As the last case requires only about 6 per cent more horsepower than the first, it will be seen that there is little to choose between any of the above types so far as overall usefulness is concerned. Other considerations, however, such as limited space, might influence the choice of a type.

Of the numerous radiators tested, among those making the poorest showing (under the conditions previously outlined) were all of the tubular type radiators and some honeycomb type radiators which had their air cells divided diagonally by sheet metal spacers or fins. Thus we observe that while the addition of fins is an advantage in the tubular type it is a distinct disadvantage in the honeycomb type.

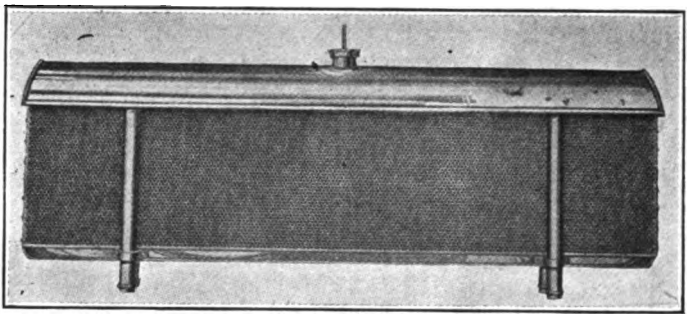
It might be mentioned that the difference in merit between these poor radiators and the good ones previously

Digitized by Google



THE CURTISS MODEL HS-2-L AIRPLANE SHOWING RADIATOR INSTALLATION

Digitized by Google



THE STURTEVANT WING RADIATOR

mentioned is very great. The efficiency of the radiators was found in many cases to fall rapidly if the flow of water was reduced to a low figure; in other cases this was found to be of less importance. Although great variation was shown by the different radiators it would appear that the flow should not be less than 0.6 to 0.7 gal. per min. per sq. ft. of surface for any type of honeycomb or plate radiator. This is a little more than is allowed on some of our large engines in this country. For tubular radiators a considerably higher rate of flow appears to be necessary. This is to be expected when we consider that the dissipation per square foot is greater for the tubular type.

This relation between dissipation and flow has an important bearing on the use of the by-pass system of regulation. A study of the curves of dissipation plotted against flow shows that while the by-pass regulation might be used successfully with one or two of the types of radiators, it will have little value in others on account of the rather sudden drop in dissipation at a certain point. On the whole, the system of shutting off the flow of air in preference to water appears to be the more reliable, as a sudden drop in temperature might cause freezing of the radiator.

The relation between depth of radiator and heat dissipation evidently varies greatly according to the design. If we consider one particular design, a honeycomb radiator using 0.354-in. square air cells, we find that the curve of dissipation rises rapidly with the depth up to about 8 in. and falls off for depths over 9 in. Thin walled tubes were found to be the most efficient, but the difference was not of consequence.

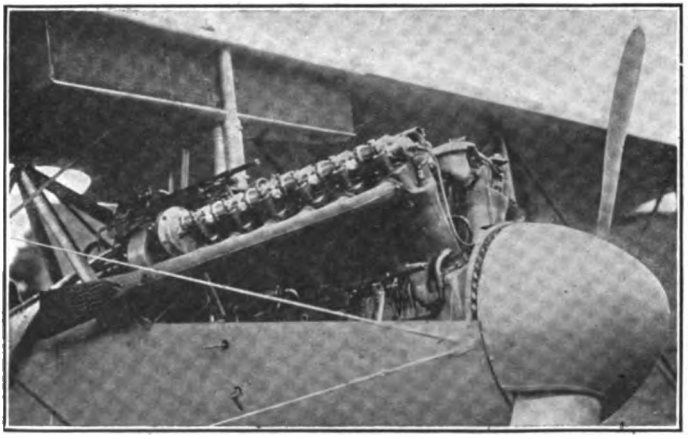
Digitized by Google

Tests made on radiators housed in the rear in a manner similar to nose installation in a fuselage showed that the radiation, as would be expected, is less than that of a fully exposed radiator. For an opening in the rear equal to 72 per cent of the air space in the radiator the dissipation was about 75 per cent that of the fully exposed radiator; for an opening equal to 32 per cent it was about 55 per cent.

Later tests appeared to show that for an opening equal to the air space the dissipation was only 65 per cent. These results should be used with caution in designing, as in testing it was not practicable to duplicate exactly conditions found in the full-size machine, such as heat radiation from the engine itself, etc.

The reports give the actual radiation and resistance for each type tested so that it is possible to calculate approximately the surface required for an installation where the radiator is not masked and where the required dissipation, air speed, flow of water and temperature difference are known. By use of the results of the fuselage nose installation and comparison of the calculations with Table 3, or similar data, the required area for fuselage installation can be approximately estimated.

The curves of radiator performances as reprinted in the *McCook Field Bulletin* (reference No. 12) have been converted to the English system of units, thus rendering



RADIATOR INSTALLATION ON THE L-W-F MODEL G-2 AIRPLANE

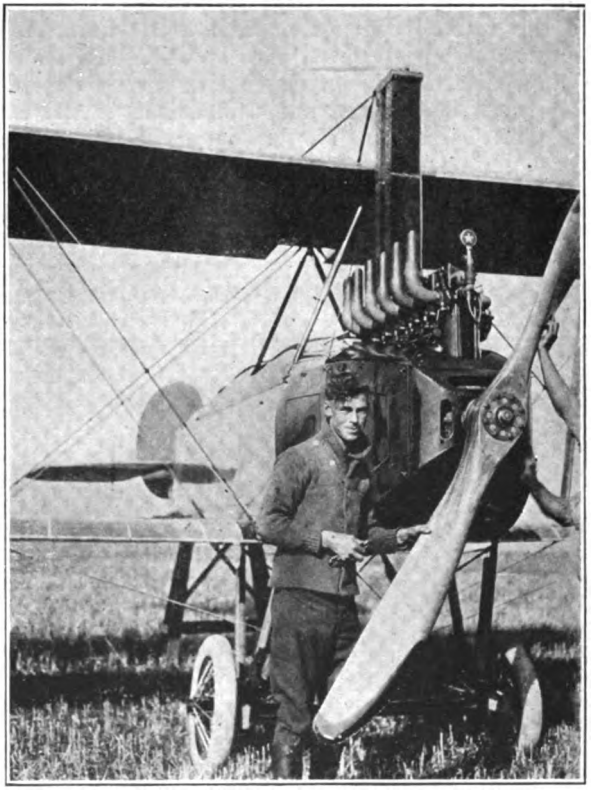
Digitized by Google

them very convenient for the average American designer who has not acquired the habit of "thinking in metric."

Heat-balance tests indicated that the heat dissipated by the cooling system, exclusive of direct radiation in an airplane, amounted to about 15 to 20 per cent of the heat value of the fuel consumed. This figure does not by any means check with the British and other test results discussed later in this paper, and I recommend using the British values until further information is received.

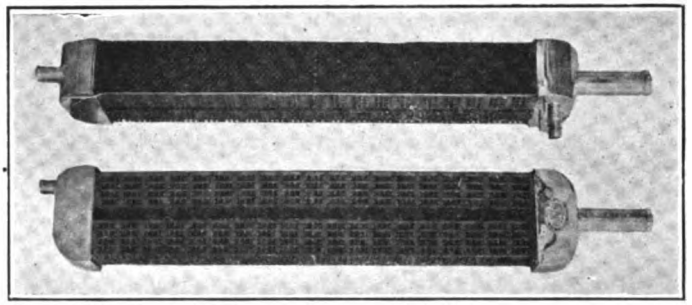
British Radiator Tests

In 1915 the British Admiralty and in 1916 the Royal Aircraft Factory conducted numerous tests on aircraft



Wright-Martin Model R Radiator Installation

Digitized by Google



THE FLEXO RADIATOR DESIGNED FOR MOUNTING ABOVE THE ENGINE AS IT APPEARS WHEN REMOVED FROM THE MACHINE

radiators. The data are in the possession of the U. S. Army and Navy and the results of the various tests are assembled and reviewed at length in the *McCook Field Bulletin,* October, 1918 (reference No. 13), and briefly in U. S. Navy Aircraft Technical Note No. 13 (reference No. 9).

As was the case with the French reports, previously referred to, these are also of a confidential nature and origin such that it is not permissible to give here as detailed a review as could be desired. However, as in the previous case, a few comments will be made and attention is called to the fact that the complete review (reference No. 13) is available to engineers of U. S. Government aircraft contractors.

A number of the radiators tested were of full size as actually used in practice, the remainder being smaller blocks made for test purposes. The results of tests on the small blocks appear to check fairly well with those on full-size radiators.

The radiators giving the greatest dissipation per unit area under equal conditions were, in order

(1) A tubular type using staggered, approximately streamlined tubes
(2) A tubular type using round tubes with spiral fins
(3) A honeycomb type formed by assembling thin water tubes bent to about "sine wave" form
(4) A full-size honeycomb radiator of almost square face and having air cells measuring 0.275 in. by 0.275 in. by 4 in. deep

The radiators giving the best all-around performance,

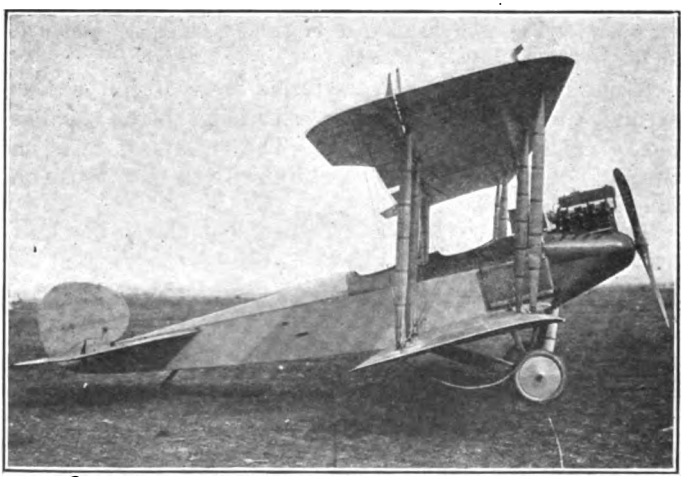
Digitized by Google

considering weight, resistance and dissipation, the speed not being stated, were, in their order of merit

(1) Full-size radiator using thin wavy water tubes set on edge and 5 in. deep
(2) Full-size radiator of flat straight tubes 1/16 in. by 9/16 in. set on edge to form strips 14 in. deep in the direction of air flow
(3) Honeycomb (small block) 0.4-in. diameter round air cells 4.75 in. deep
(4) Honeycomb (small block) 0.35-in. diameter round air cells 4 in. deep
(5) Honeycomb (small block) 0.475-in. diameter round air cells 4 in. deep

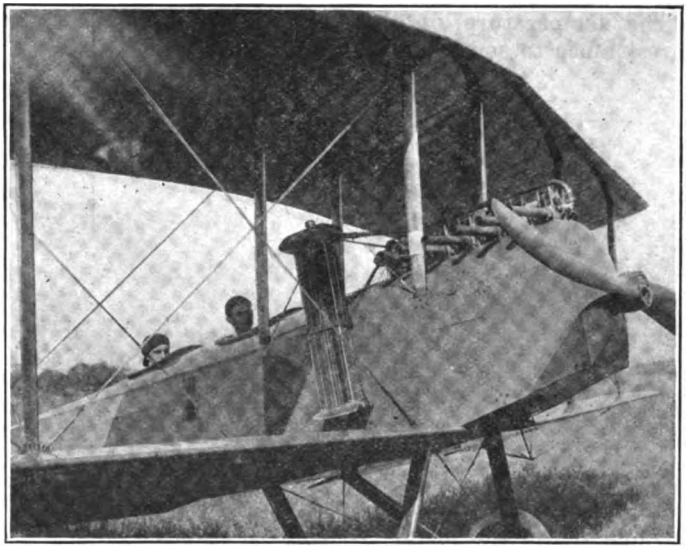
As the range of difference is between 6 and 7 per cent there is little to choose between these so far as merit is concerned.

A full-size radiator with a hole in the center, for the extension of the crankcase on the propeller end of the engine, and similar to the ordinary type installed in front of the engine, was tested. This radiator showed a merit of only about 80 per cent that of a square radiator without the hole and having the same type of radiation. Designers are cautioned, however, against drawing too general conclusions from this single test.



THE AEROMARINE TRAINING MODEL EQUIPPED WITH SIDE RADIATORS

Digitized by Google



AN EARLY STANDARD MACHINE SHOWING THE SIDE RADIATORS

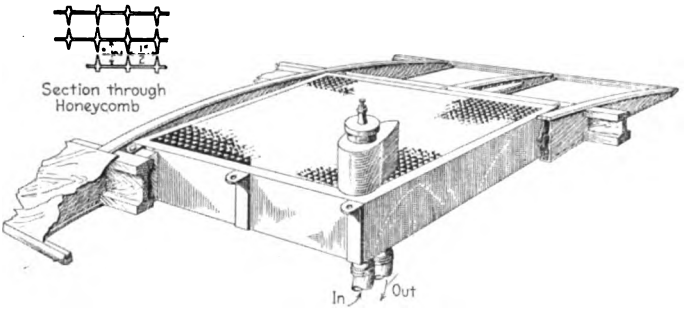
Two types of radiators designed for installation on the side of a fuselage, and formed of staggered blocks of radiation, showed merit values of about 73 per cent and 62 per cent that of the best honeycomb radiators of the conventional type. This same pair of radiators dissipated heat per unit area at almost exactly the same rate as conventional radiators with the same type of radiation. Their resistances, however, were 42 per cent and 28 per cent greater for equal dissipation, which comparison only applies to the same type of radiation and at 60 miles per hr.

Honeycomb radiators having 0.275-in. air tubes gave the best results for low speeds, but the increase in resistance gives this type a disadvantage at high speeds. For very high speeds the plate type appears to have the advantage over the honeycomb type. For honeycomb radiators a ratio of diameter to length of air cells of 1:9 is recommended for 50 miles per hr. and 1:14 for 80 miles per hr.

Resistance increases as the square of the speed over the range with which we are concerned. Dissipation of heat increases as the nth power of the speed. The exponent

Digitized by Google

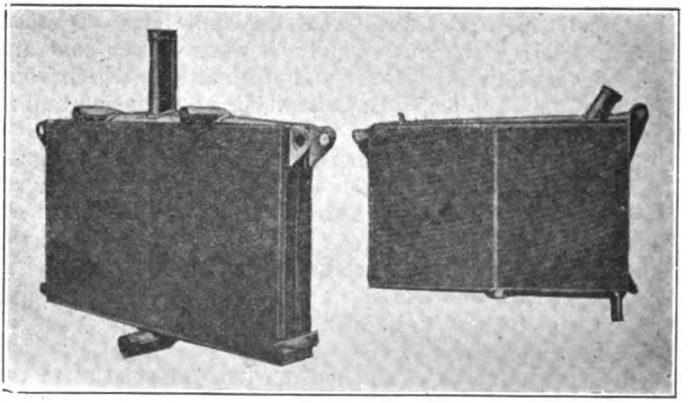
$n = 0.9$ and shows a tendency to increase with the speed. The temperature of the radiator also increases the resistance to some extent.



THE L-W-F EXPERIMENTAL WING-CURVE RADIATOR FOR MODEL G-2 AIRPLANE

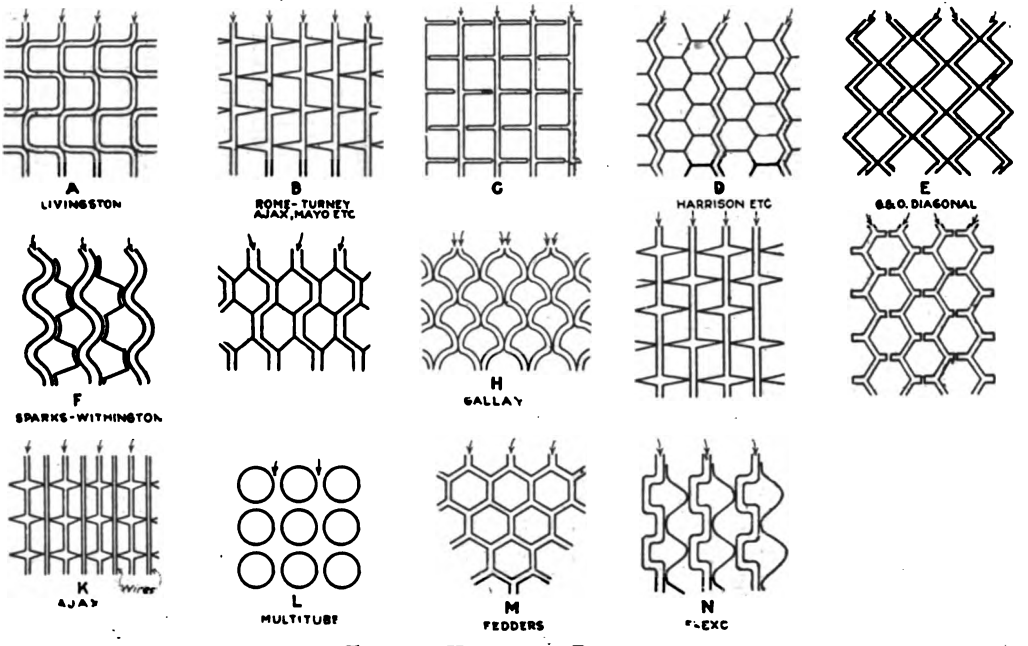
Square front radiators apparently possess a slight advantage over the oblong type both in lower resistance and increased dissipation. Yawing increases both dissipations and resistance for moderate angles, up to about 30 to 40 deg.

On the whole, the better types of honeycomb, flat tube or plate radiators are very satisfactory, but it should be noted that the difference between the good and bad is very great. All round water-tube radiators are out of



MULTITUBE RADIATORS USED ON DIRIGIBLES

Digitized by Google



TYPES OF HONEYCOMB RADIATION
These Are Drawn Slightly Out of Scale to Show the Water Passages Clearly

Digitized by Google

question as was shown also in the French tests. It was recommended that round tubes of 10-mm. (0.394-in.) diameter and 120 mm. (4.73 in.) long be adopted as standard for the construction of honeycomb radiators. This has since been done.

The report suggested that the reserve water supply in gallons be about equal to

$$1 + \frac{\text{horsepower} \times \text{hours duration}}{1600}$$

For a machine of the DH-4 Liberty class having about 4-hr. duration this would give about 2 gal. of reserve water. This is slightly in excess of the amount which I have been accustomed to allow, but on the other hand, radiators designed by me were usually fitted with a safety valve set to release at about 3 to 4 lb. per sq. in. This, no doubt, reduced the evaporation and loss of water greatly.

Vibration, such as exists in the average airplane when the engine is running, was found to increase dissipation. Pending further experiments, this increase can be taken as being close to 10 per cent.

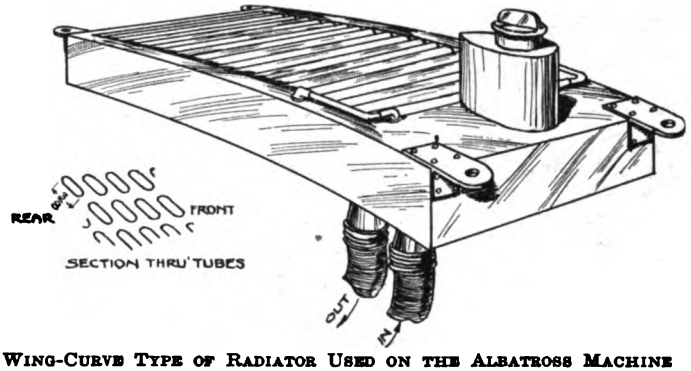
The British Admiralty reports appear to favor the by-pass system of regulation of cooling, but as the tests apparently did not include any on the effects of reduced water flow, the French results should be given more weight.

Heat-balance tests on four aircraft engines in a 60 miles per hr. wind showed that the value in horsepower of the heat dissipated by the cooling system is within 2 to 3 per cent of the brake horsepower of the engine. For all practical purposes the horsepower dissipated in heat by the radiator can be taken as 1.02 times the brake horsepower of the engine. This figure appears to check with other tests (reference No. 14) closer than the French figures do, and considering the fact that the engines were exposed to a strong wind it may be taken to be the most reliable which we have up to date, at least until more information regarding the French tests is received. It should be noted, however, that the percentage of heat units carried away from the jackets may not be the same at altitudes.

Bureau of Standards Tests

For some time past the Bureau of Standards at Washington has been conducting, under the supervision of the

Digitized by Google



WING-CURVE TYPE OF RADIATOR USED ON THE ALBATROSS MACHINE

sub-committee on powerplants of the National Advisory Committee for Aeronautics, an investigation of the performance of aircraft radiators. The reports are available for reference and will be published very shortly (references Nos. 23 to 27). Some interesting results have been accomplished and a few notes on these are given.

A series of tests was made to determine the effects on the resistance of an airplane, of installing the radiator on the nose of the body. The resistance of a one-quarter size model body was tested in the wind tunnel under three conditions and the results of test are given herewith in Table 4.

TABLE 4—RESISTANCE OF ONE-QUARTER SIZE MODEL BODY

Case No.	Condition	Resistance in lb. at 60 miles per hr.	Ratio of resistance to that of Case 1	Ratio of resistance to that of Case 2
1	Body without radiator and crudely streamlined	1.7	....	....
2	Body with radiator in place on nose but covered with paper	3.6	2.12	....
3	Same as case 2 except that forward part of body was furnished with vents and radiator was left clear so that air could pass through	5.6	3.30	1.55

From this test we can make the following notes:

The resistance of full-size bodies at the same speed would be sixteen times the figures given and can be assumed for all practical purposes to increase with the square of the speed. As the necessity for use of shutters on the radiator becomes important only at high speeds,

Digitized by Google

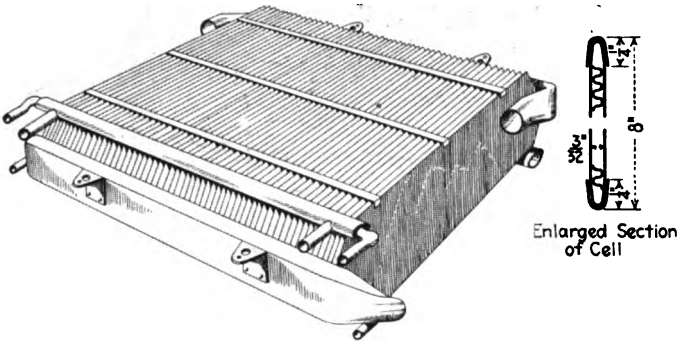


PLATE TYPE OF RADIATOR WHICH IS SET INTO CURVE OF THE UPPER WING ON LE PERE MACHINES

let us investigate the reduction in resistance, assuming that we are able to fly with the shutters entirely closed, a condition, however, which is somewhat more advantageous than is actually attained in practice.

For full size machines

Resistance at 60 miles per hr. =

$$\begin{cases} \text{Case 2} = 3.6 \times 16 = 57.6 \text{ lb.} \\ \text{Case 3} = 5.6 \times 16 = 89.6 \text{ lb.} \end{cases}$$

Resistance at 130 miles per hr. =

$$\begin{cases} \text{Case 2} = 3.6 \times 16 \times \dfrac{130^2}{60^2} = 271 \text{ lb.} \\ \text{Case 3} = 5.6 \times 16 \times \dfrac{130^2}{60^2} = 421.5 \text{ lb.} \end{cases}$$

Thus we find that if we could operate a machine at, say, an altitude of several thousand feet with *all* the shutters closed we could reduce the resistance of the body by 150.5 lb., or 35.7 per cent. Translating this into horsepower saved, we have

$$\frac{150.5 \times 5280 \times 130}{33{,}000 \times 60} = 52.2 \text{ hp.}$$

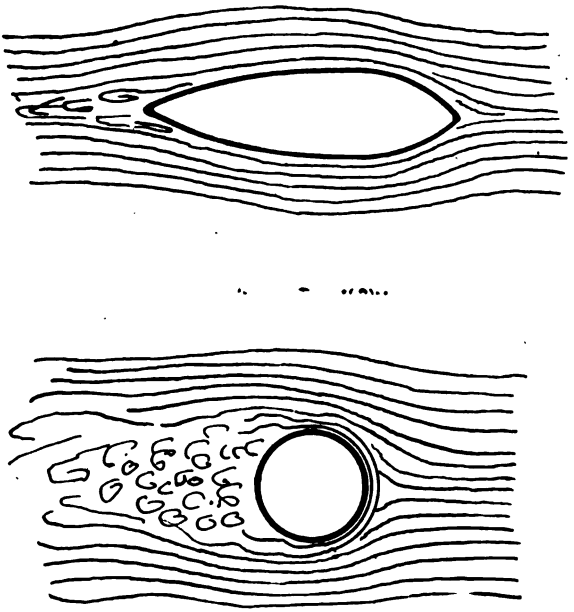
Although this ideal condition cannot be attained in practice, the figures have been given to illustrate the importance of furnishing fuselage nose radiators with shutters and using them not only to maintain the engine at its best operating temperature, but also to reduce the resistance of the body at the very time when such reduction is of the greatest importance.

A test was made of Case 3 to determine the speed of air through the radiator, and this was found to be 27

Digitized by Google

miles per hr, as against 60 miles per hr., the speed of the air in the tunnel. This apparently shows that the higher resistance of the model with the open radiator and vents is due to work being done in removing part of the kinetic energy from the air, or, as is the case with the full-size machine in flight, forcing the air to move at 33 miles per hr. in the same direction as the machine.

Radiation from fins and similar surfaces not in actual contact with the circulating water was found to be of value only for a short distance out from the water space, and they are not as advantageous as surfaces in actual contact with the water. Consequently the use of stiffening wires, strips, etc., add to resistance without increasing radiation and should be avoided. Furthermore, it seems that the radiating surfaces should be practically continuous from front to rear. It was found that so-called "dead water radiation", surfaces not in



FLOW OF AIR AROUND STREAMLINED AND ROUND SECTIONS

contact with moving water, radiates slightly less for the same area than surfaces in contact with the water flow. The percentage of air which flows through a honeycomb

Digitized by Google

radiator was found to be very nearly equal to the percentage of space open to air flow in the radiation. The rest of the air obviously flows around the radiator. The numerical value of the air flowing through the cells was found to be 70 to 85 per cent (80 per cent being probably a fair average) of the air which would be expected to strike the face area of the radiator.

Miscellaneous Tests

The following notes on results of miscellaneous experiments will probably be found of interest and assistance:

Streamlined tubes exposed to moving air were found to radiate 1.4 times as much heat as round tubes for the same actual surface and air speed. This figure, it should be noted, makes no allowance for the decreased resistance. As streamlined tubes are narrower than round tubes of the same surface and have considerably less resistance than round tubes of equal width, it will be readily seen that the streamlined tube possesses very great advantage in practice. The information came from one of the assistants at the Bureau of Standards, the original source not being mentioned at the time.

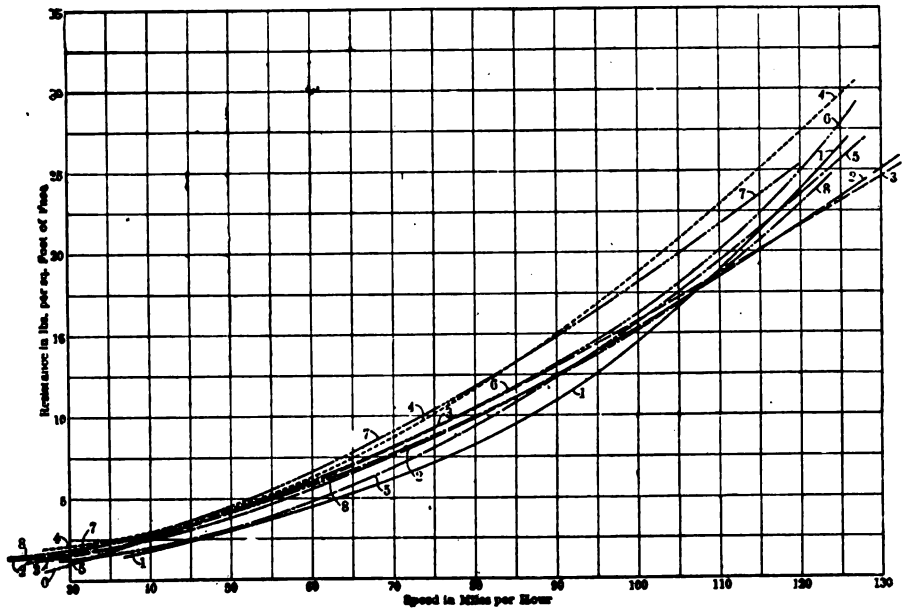
This phenomenon of the streamline tube radiating more heat than the round one under similar conditions is probably accounted for by the regularity of flow around the streamlined tube. The approximate flow of air around streamline and round sections, as recorded photographically by the National Physical Laboratory in England, (reference No. 39), is shown in one of the illustrations. It will be noted that the air remains in contact with the streamline surface for a much greater distance than it does with the round surface.

A series of tests was conducted by the Washington Navy Yard (reference No. 42) on eight sections of honeycomb radiation supplied by various manufacturers, the results of which are shown graphically.

From the curve of resistance in pounds plotted against speed in miles per hour, it will be seen at a glance that the resistance increases with a power greater than unity. From the curves and our knowledge of air resistance we may note that the equations will be the form $P = KAV^n$, or, for unit area, $P = KV^n$, where

P = head resistance
K = a constant for each type of radiator
V = speed
n = exponent of V

Digitized by Google



RESISTANCE CURVES OF HONEYCOMB TYPE RADIATORS

Digitized by Google

Selecting values from each of the curves to give simultaneous equations and solving for n shows that this exponent varies between the limits 1.876 and 2.280 and averages 1.990, or practically 2. This calculation was based on another set of curves plotted from the same data.

Another curve shows the horsepower equivalent of heat dissipated per 100 deg. fahr. temperature difference, per square foot of frontal area, plotted against air speed in miles per hour. It will be noted that, considered from this angle, the various makes of radiation do not perform similarly, the dissipation increasing in some cases with a power less than unity, while in other cases the exponent is greater than unity.

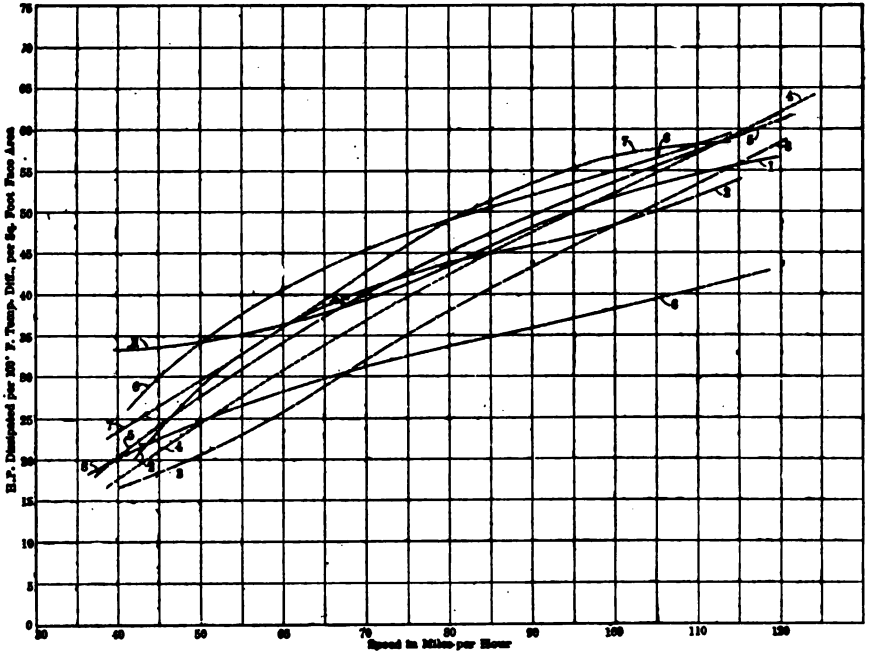
The "figure of merit" for each type of honeycomb at different speeds, plotted against air speed in miles per hour is also shown. The so-called "figure of merit" is the value obtained by dividing the horsepower dissipated, by the horsepower required to carry and to overcome the resistance of 1 sq. ft. of radiation moving through the air at any given speed, and is therefore an approximate but useful measure of the efficiency of the radiation. It will be noted at once that a section may be well suited for a certain speed but unsuited for another; also, that certain makes of the honeycomb radiation possess marked advantage at low speeds, but at high speeds, so far as efficiency is concerned, there is little to choose between any of them, as their performance is very nearly the same. Other characteristics may, however, determine the choice of radiation.

Discussion and Data

Before entering into any discussion it seems advisable to lay great stress on the fact that all radiator calculations should be considered to be only approximations. So many variables enter into the case and our data are even yet so incomplete that exact results cannot be obtained.

Bends in Pipes As a general rule all unnecessary bends in water pipes or radiation should be avoided, as these offer resistance and reduce the rate of flow. It should be remembered that the use of centrifugal pumps for circulating water is probably universal, and with this type of pump any increase of resistance in the system will decrease the flow of water. The French tests showed that it is important with most types of radiation to keep the rate

Digitized by Google



CURVES SHOWING THE DISSIPATION OF HEAT BY HONEYCOMB TYPE RADIATORS

Digitized by Google

of flow high. In any case, if the flow is allowed to drop considerably the result will be a reduction of the temperature difference between air and water, with a proportionate reduction of dissipation.

Location of Radiator The question of radiator location cannot by any means be said to be definitely settled as yet. There is wide diversity of opinion among engineers on this subject. The British claimed a few months ago that they could find very little difference in machine performance when using different locations for the radiator. They recommended that the radiator be installed on the fuselage nose when this can conveniently be done.

The tendency today seems to be to place the radiator in the upper wing. Whether the wing curve radiator is to prove the ultimate form cannot be said as yet. Some full-scale flight tests made under the direction of the Navy Bureau of Steam Engineering appear to show that the resistance of wing curve radiation is not nearly as low as we might expect. Wind-tunnel tests should throw some light on this.

Ensign Swenson, U. S. N., who has charge of radiator work for the Navy Department, makes the following recommendations:

(1) On tractor flying boats the radiators should be located in the slip-stream, as without consideration for other factors, the ability to "taxi" will be nullified if they are placed elsewhere. If the engine is not housed in, the best location is probably between the engine and the propeller; if the engine is housed in, place the radiator or radiators next to the nacelle but a few inches away from it

(2) On pusher flying boats the same recommendations hold, with the exception that the slip-stream is not available for cooling

(3) On small seaplanes and small land machines locate the radiators anywhere in the immediate vicinity of the engine, with this exception

(4) Do not install the radiator in the nose

(5) On large multi-engined land machines locate the radiators in one or two groups out of the slip-stream

The tendency at McCook Field seems to favor a plate type of radiator set on edge in the upper wing.

From what information we have to date I am strongly of the opinion that the best type of radiator installation depends as much upon the general design, type and speed of the airplane as upon other considerations. I am in-

Digitized by Google

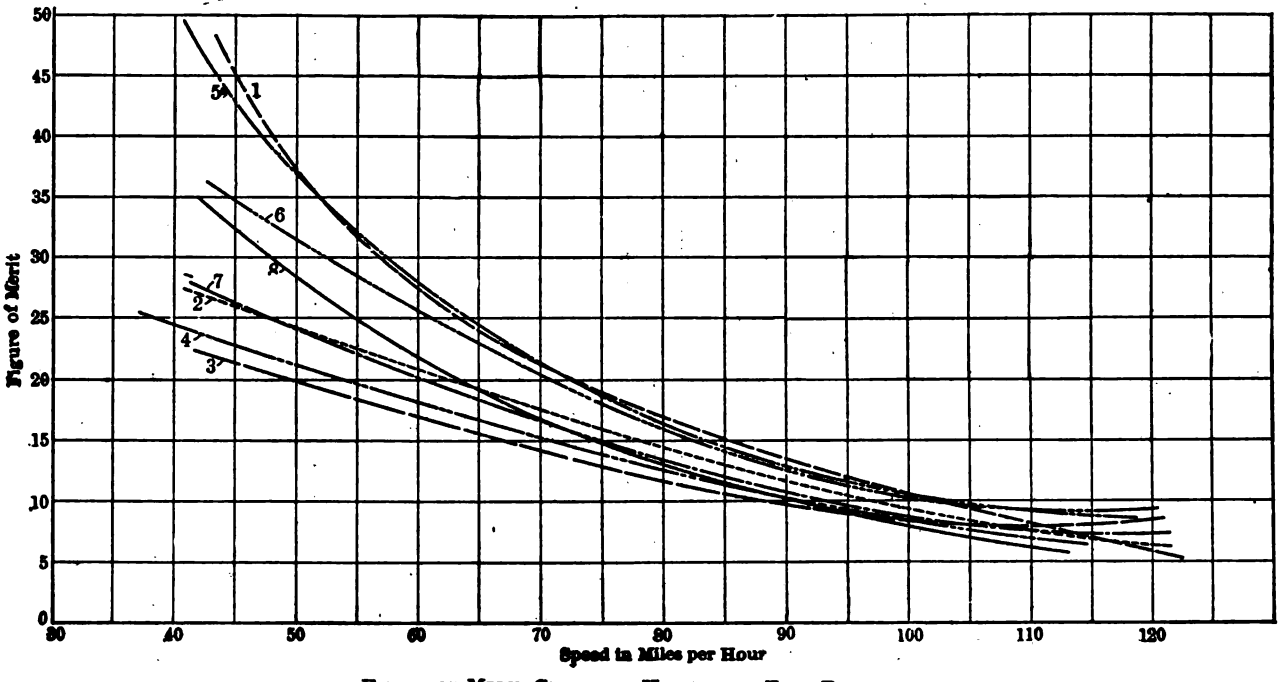


FIGURE OF MERIT CURVES OF HONEYCOMB TYPE RADIATORS

Digitized by Google

clined to expect more of a radiator mounted so that it can be drawn into the wing or body than of any other method of installation. Such an installation does not require the air to change its direction to any extent when flowing through the cells, thus keeping efficiency high and resistance low. This, combined with the feature of exposing only as much radiation as is actually required at the time, would make it very efficient. When gliding, the entire radiator could be drawn in, thus improving the angle of glide. At the same time there is much to be expected of the wing curve type of radiator if provided with a shutter, so that when the radiator is covered up there is practically a wing curve in its place.

It should be added that for low-speed machines there is probably little to choose between any of the different locations. There certainly is less to choose between them for low speeds than for high. This is because resistance varies approximately as the square of the speed, while dissipation of heat varies with nearly the first power of the speed.

For the present I would recommend that in new designs, where some choice of location is open, radiators be calculated for two or three different types of installation and studied from every angle before the question is settled. In any case, the radiator should be partly or wholly in the propeller slip-stream; otherwise it will be difficult to operate the engine on the ground or to "taxi" the machine.

Alex. Klemin found by wind-tunnel tests (reference No. 18) that a body similar to a radiator decreased the lift-drift ratio less when located on the lower side of the wing than on the upper. As, however, we know nothing about the air flow, this information is of little assistance to us.

Effects of Altitude on Radiator Performance When an airplane reaches a high altitude two new conditions are encountered, lower density and lower temperature of the air. Both affect radiation, the former decreasing and the latter increasing it. The former also decreases the brake horsepower of the engine if a compressor is not used to supply air at constant pressure, which I do not believe has been done successfully as yet. We are using, however, makeshift devices in the form of adjustable carbureters and also extra high compression engines which no one is supposed to run wide open at low altitudes, although the temptation to do so is very strong.

Digitized by Google

At any altitude the size of the radiator required is determined by the conditions in the climb at maximum rate, and, as the horsepower developed by the engine is greatest at low altitudes, we find that radiator size is governed by the conditions in maximum climb at a low altitude.

As the load on the wings is practically constant during a climb we can conclude that the horizontal speed during this climb varies inversely as the density of the air. This is shown by our fundamental formula in aerodynamics, Bernouilli's theorem, in which density appears as a factor in the first power. This being the case, the number of pounds of air passing through a radiator not in the slip-stream, in a given time will be constant throughout the climb irrespective of the horizontal speed, which is increasing. We know from French experiments that the dissipation of heat varies directly as the density, and therefore as the pounds of air passing through the radiator, so we may conclude that dissipation of heat during a climb, at maximum rate, will vary only with the temperature difference. The foregoing conclusions enable us to calculate Table 3, giving the percentage of our radiating surface that will be required at altitudes for constant horsepower and constant margin between operating temperature and the boiling point of water.

Knowing then the performance at any altitude of the particular engine under consideration, we can obtain the approximate area required during climb by the formula

$$\left.\begin{array}{c}\text{Area during}\\ \text{climb at any}\\ \text{given altitude}\end{array}\right\} = \frac{\text{Total area} \times \text{factor} \times \text{horsepower at altitude}}{\text{horsepower at sea level}}$$

and the area required for high speed at any altitude by the formula

$$\left.\begin{array}{c}\text{Area during high}\\ \text{speed at any}\\ \text{given altitude}\end{array}\right\} = \frac{\text{Area for climb} \times \text{climbing speed}}{\text{high speed}}$$

These formulas do not apply in the form given to radiators located in the slip-stream, but the factor for constant horsepower multiplied by total area will give nearly the area required for this condition if the engine has no altitude adjustment.

If the engine is not equipped with an adjustable car-

Digitized by Google

bureter or similar means for adapting it to operation at altitudes, the horsepower at any altitude can be obtained by aid of a curve of "effect of altitude on the horsepower of a gasoline engine" (such as reference No. 34). This curve enables us to add to Table 5 the lower figures, which represent the fraction of radiating surface required for an engine provided with absolutely no means of adjustment for altitude.

Air Bubbles in Cooling Water It is important to guard against the possibility of air being drawn into the circulating system along with the water, as this results in a great decrease of efficiency (reference No. 5). This is not a very common trouble, but it may happen in a poorly designed system in which the water entering the radiator is allowed to splash or bubble violently. The trouble can be avoided by proper placing of the inlet or by the use of a baffle plate.

Design of Water Pockets, Etc. Large water pockets should be avoided, as they merely add to the weight. Water pockets should be only of sufficient size to provide free circulation of the water. Care should be taken in the designing of water pockets that the water entering the radiator is distributed equally to all parts of the honeycomb. This can be accomplished by the use of baffle plates to deflect and distribute the water in the desired direction.

An expansion and reserve water tank must always be provided at the highest point in the cooling system. The capacity for a given installation with an open overflow can be calculated from the British data given earlier in this paper. In cases where the top of the radiator is the highest point in the cooling system it is customary to incorporate the expansion and reserve water tank in the upper water pocket of the radiator.

Where a hole is cut out of the center of the honeycomb to provide for the crankcase extension, a water pocket must be provided to carry the water from the upper part of the honeycomb to the lower. The area of the cross-section of this pocket should be equal to or slightly greater than the area of the water passages in the part of the honeycomb removed.

Velocity of Air in Slip-Stream In our radiator calculations it usually becomes necessary to estimate the speed of the air in the slip-stream of the propeller. As this speed is dependent as much upon the design of the particular propeller as upon the other factors, we cannot give any rule which applies equally well to all cases.

Digitized by Google

TABLE 5—FACTORS FOR OBTAINING RADIATING SURFACE REQUIRED AT ALTITUDES

Mean Temperature Difference Between Air and Cooling Water at Sea Level, Deg. Fahr.	Altitude in Ft. 0	5,000	10,000	15,000	20,000	25,000	30,000
	Boiling Temp., Deg. Fahr. 212	203	194	185	176	167	158
	Temp. Drop of Air, Deg. Fahr. 0	17.0	33.0	46.8	58.0	67.2	75.6
	Horsepower 1.00	0.8625	0.735	0.620	0.520	0.435	0.365
50	1.00	0.8620	0.769	0.716	0.694	0.693	0.699
	1.00	0.7440	0.565	0.444	0.361	0.302	0.355
75	1.00	0.9030	0.833	0.791	0.773	0.772	0.776
	1.00	0.7790	0.612	0.490	0.402	0.336	0.383
100	1.00	0.9260	0.870	0.835	0.820	0.818	0.822
	1.00	0.7990	0.640	0.518	0.427	0.356	0.300
125	1.00	0.9400	0.893	0.863	0.850	0.849	0.852
	1.00	0.8110	0.657	0.535	0.442	0.369	0.311
150	1.00	0.9500	0.909	0.883	0.872	0.871	0.875
	1.00	0.8190	0.668	0.547	0.454	0.379	0.319

NOTE:

(1) Upper figures are for constant horsepower and radiator not in the slip-stream of propeller

(2) Lower figures are for engine not equipped with any means of adjustment for altitudes and radiator not in slip-stream

(3) Upper figures are also nearly correct for engine not equipped with any means of adjustment for altitudes and radiator completely in the slip-stream

(4) All figures based on climb at maximum rate and constant margin between operating and boiling temperatures, with radiator under atmospheric pressure only

Digitized by Google

A number of tests have been made by M. Eiffel with a view to obtaining information on this subject, and E. P. Warner of the National Advisory Committee's staff has made a study of the results obtained. A curve based on some of the Eiffel experiments is reproduced and can be used to obtain approximately the speed of air in the slip-stream, the Eiffel No. 9 propeller on which it is based being assumed to be typical.

To use this curve it becomes necessary to know the speed of advance corresponding to the maximum efficiency of the propeller. If it happens that we do not know, at the time of designing our radiator, exactly what this speed is going to be, it becomes necessary to resign ourselves to another approximation. The relation of this speed to the maximum speed of the machine will depend very largely upon whether the propeller is designed to give great climbing ability, high speed or a compromise between the two. As it is advisable to err on the low side rather than on the high side in estimating the speed of air striking the radiator, Mr. Warner suggests that the speed of advance at which the propeller shows its highest efficiency be assumed to be 90 per cent of the maximum speed of the airplane.

Thus for a typical case of an airplane having a maximum speed of $V = 130$ miles per hr. we have $V_e = 117$ miles per hr. For high speed $V/V_e = 1.11$ and $V_s/V = 1.14$. Thus the slip-stream velocity *relative to the machine* at high speed is 130×1.14 or 148 miles per hr. This is probably slightly on the low side of the actual speed for most machines.

It should be noted here that the velocity of slip-stream relative to the atmosphere is very low at high speeds; in the foregoing case it is 18 miles per hr. However, we are only concerned with the speed relative to the airplane.

Forward Speed of Machine During Climb at Maximum Rate Where possible this should be obtained from the curves of estimated performance, or from the actual performance of similar machines. In case this is not convenient it might be noted that the French found the forward speed during a climb at maximum rate varied from 56 miles per hr. for the slower service types to 78 miles for the faster types. It will be noted that the range of speeds is not great, which is not surprising when we consider that the landing speeds do not vary greatly.

Digitized by Google

The landing speed of a machine has an important bearing on its forward speed during climb at maximum rate.

The speed during climb at maximum rate can be obtained very roughly by the formula

$$\left.\begin{matrix}\text{speed in climb at}\\ \text{maximum rate}\end{matrix}\right\} = \text{low speed} + \frac{\text{high speed} - \text{low speed}}{4}$$

Mean Temperature Difference Between Air and Water Before proceeding with any radiator calculations it becomes advisable to know the difference between the mean temperatures of the cooling water and the air. If the exact flow of water and horsepower equivalent of British thermal units carried away from the cylinders is known, the temperature drop of the water can be readily calculated. When this is not known the temperature drop in the radiator, or rise in the cylinder jackets, can be assumed to be about 20 deg. fahr. This value is taken from block test results (reference No. 14). Thus we have the mean temperature of water equal to about 10 deg. fahr. less than the temperature of outlet from the cylinders.

The mean temperature of the air is almost impossible to obtain beforehand. Fortunately, it appears not to be essential, as the French found (reference No. 12) the assumption that the mean temperature equals the initial temperature introduced only a very slight error.

Thus the mean temperature difference in degrees fahrenheit can be taken as approximately equal to

(temperature of cylinder outlet)—10—(temperature of air)

The British recommend (reference No. 13) that designers provide for a temperature difference, in temperate climates, of 144 deg. fahr. (62 deg. cent.). This would correspond to about 46 deg. fahr. for the air and about 200 deg. fahr. for the water outlet from cylinders and is by no means suited to even our northern United States summer conditions. I recommend that for summer conditions a temperature difference of 110 deg. fahr. be not greatly exceeded. This corresponds to 190 deg. fahr. for water and 70 deg. fahr. for air.

Pressure System The pressure system, which I believe I originated, consists of the ordinary cooling system provided with steam-tight caps and a safety valve. The safety valve is placed at the highest point of the system and can be set to "blow off" at from 3 to 4 lb. per sq. in. without risk of injuring the radiator.

Digitized by Google

This system has two distinct advantages: (*a*) The loss of water by splashing or evaporating is eliminated, and (*b*) the boiling point of the water is raised slightly, thus tending to eliminate troubles due to boiling in unusually hot weather. The addition of 3½ lb. per sq. in. to the atmospheric pressure at sea level raises the boiling point of water from 212 to 222.8 deg. fahr. The two results make it possible to eliminate nearly all of the reserve water ordinarily carried.

This system was first used on the L-W-F model V-3. The machine was provided with a radiator suited to our northern United States climate and when used down in Texas it was found that the rapid evaporation of water limited the duration of flight to less than 2 hr. After the installation of the safety valve it became possible to fly the machine until the fuel tanks were emptied, or more than 6 hr. This demonstration caused my associate, Mr. Mitchell, and myself to adopt the pressure system as standard practice on L-W-F machines.

Weight of Radiators The weights of the sections tested by the British and French are given in their reports (references Nos. 12 and 13) and the weights of a number of typical American makes of honeycomb radiation are given in Table 1. The weights of a number of complete radiators are given in Table 3. These vary from 0.302 to 1.180 lb. per b.hp., and average about 0.634 lb. per b.hp. As several radically different types are included, the latter figure can safely be used for the purposes of preliminary estimate. It should not be forgotten, however, that the weight will vary greatly according to the design, and closer estimates can be obtained if figures are based on similar designs selected from Table 3.

Materials of Construction A good grade of brass is more satisfactory than copper for the construction of the honeycomb. Ensign Swenson of the Bureau of Steam Engineering, Navy Department, recommends 85-15 per cent brass, while Mr. Sage of the Rome Turney Co. recommends 65-35 per cent brass for honeycomb construction. Copper shows a tendency to become brittle and to crack at the folds after it has been in service for some time. The material in use ranges from 0.003 to 0.008 in. thick; 0.004 to 0.005 in. is recommended.

The material used for water pockets should be brass. The thickness will vary a little according to the design of the radiator, but in general Nos. 18, 20 or 22

Digitized by Google

B & S gage are very satisfactory. Ensign Swenson recommends the use of the last two gages.

Production Considerations Water pockets necessitating drawn, hammered or pressed parts should be avoided, particularly in the case of small production.

When honeycomb radiation is used the "block" of radiation should be square or oblong wherever possible. Round or angular corners introduce hand-work in fitting, with a consequent increase in cost, and should be avoided. This remark, however, does not apply to radiation built up out of small tubes, such as the Harrison tubular, Multitube, etc., as the shape of the block makes very little difference in this case.

Radiators of the Albatross type are very expensive to produce in small quantities. This does not apply, however, to quantities sufficient to justify the manufacture of the large dies necessary.

Adjustment of Radiation Means of adjusting the amount of radiation while in flight possess considerable advantage. This adjustment can be made in two general ways:

(1) By regulating the flow of water through the radiator with the aid of a by-pass or a throttle
(2) By regulating the flow of air through the radiator

Both methods have been used successfully, but the first introduces the danger of freezing the water in the radiator and, as shown in the discussion of results of French tests, does not operate satisfactorily with most types of radiation.

The second method can be applied in various ways:

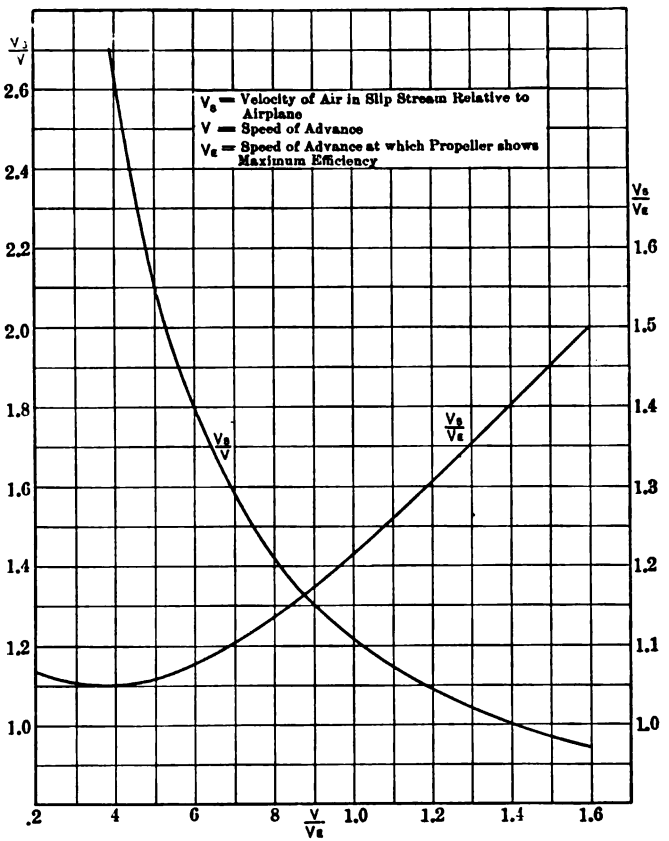
(1) By the use of shutters or a curtain in front of the radiator. Each of these methods as used on the German Gothas is shown (reference No. 40)
(2) By drawing the radiator partly inside of the body of the machine
(3) By pivoting the radiator so that it can be set at varying angles to the air. This method has been used on some of the De Haviland planes

No one of these several methods can be selected as the best since the choice of any one is dependent upon the installation of the radiator. In the case of a radiator located on the fuselage nose, the shutter system is the most suitable, as the resistance of the body is decreased when the shutters are closed. In the case of wing-curve radiators, a sliding curtain mounted on a

Digitized by Google

roller similar to a shade roller would appear to be most suitable. Although this has not been used up to date, a modification consisting of a flat sliding shutter has been used on the German Halberstadt machine (reference No. 19). Wing-curve radiators located out of the propeller slip-stream would be expected to be partly self-regulating as the radiator lies at a slightly larger angle to the air during a climb than during high speed. This would not apply to cases where the radiator is entirely in the propeller slip-stream as no change in the angle presented to the air would then take place.

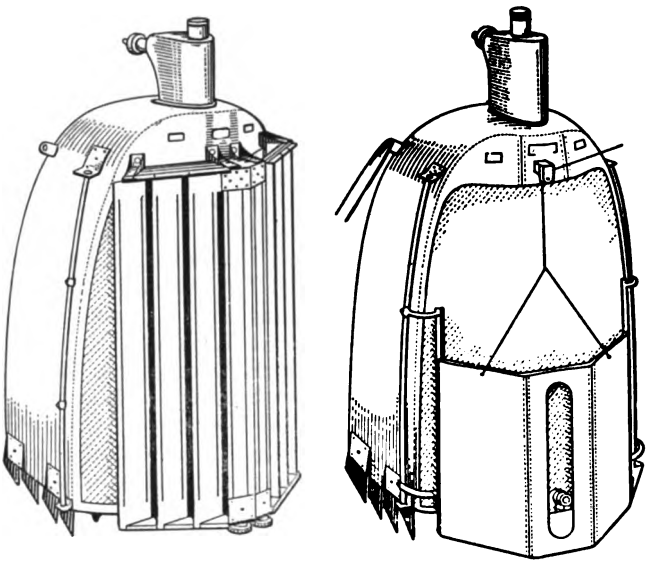
In the case of radiators located on the side of the body,



CURVES OF THE RELATION BETWEEN VELOCITIES OF ADVANCE AND OF SLIP-STREAM FOR THE EIFFEL NO. 9 PROPELLER

Digitized by Google

or engine nacelle, either shutters or the withdrawing of the radiator into the body would be suitable. In the case of radiators located clear of the body, such as on the nose of the upper wing, the use of a by-pass, or of a



SHUTTERS USED ON RADIATOR OF GOTHA MACHINES

streamlined housing which could be almost entirely closed, would be the most appropriate, as shutters or a curtain would increase the resistance of the radiator. If a by-pass is used it should be adjusted so that it cannot eliminate all of the flow through the radiator; otherwise freezing trouble is certain to be encountered at altitudes. A type of radiation must be selected also which shows a large and gradual drop in dissipation with reduction of flow.

In any case the controlling device should be operated from the pilot's cockpit and constructed so that if possible, in case of anything going wrong with it, the shutters or curtain will be held in the "open" position automatically. In the case of a by-pass, it should be arranged to send all of the water through the radiator if trouble occurs.

A thermostatic regulator for controlling the flow of

Digitized by Google

water through the radiator has been used on the Sturtevant 210-hp. airplane engine.

Shutters operate most satisfactorily when they are between 1 and 2 in. wide; 1½ in. is a good figure. They should be rigidly constructed to hold their shape under the air pressure in flight, and should be of streamline form. By pivoting shutters near their front edge they can be made to open automatically by the air pressure.

Tests for Finished Radiators Finished radiators should be tested for leaks before being installed. The most satisfactory way to make this test is to totally submerge the radiator in water while an air pressure of 5 to 8 lb. per sq. in. is maintained inside the honeycomb and pockets by an air-pump. The slightest leak will be shown by air bubbles rising from it.

It is not advisable to make this test with a pressure of less than 5 lb., as weak spots in the soldering may not be detected; nor is it advisable to exceed a pressure of 10 lb. as the radiator is liable to be damaged.

It is also well to test the flow of water through a radiator, although trouble from obstruction to flow is not common in a new radiator if the design be reasonably good. The British require a radiator to be capable of passing 7.5 gal. of water per sq. ft. of frontal area per min. under a pressure of 4 lb. per sq. in.

The Bureau of Steam Engineering of the U. S. Navy requires that radiators be stored for 14 days after testing and again subjected to the pressure test (reference No. 20).

Conclusion

In preparing this paper the original intention was to include some examples of application of the data to actual designs and some comparisons with practice. Because of the length of the paper, however, and the ground already covered, it appears advisable to leave this until a later date, particularly in view of the fact that the British and French figures could not be made public. It may be mentioned that a few attempts have been made to apply the experimental data directly to practice, and the results do not check well with past experience. However, while these attempts were not sufficiently thorough to justify the passing of judgment on the value of the data, it is strongly advised that any new design be compared with such data and that for the present these data be given preference.

In conclusion I wish to thank the various radiator

Digitized by Google

manufacturers,[8] Dr. Dickinson of the Bureau of Standards, Ensign Swenson, U.S.N., and E. P. Warner of the staff of the National Advisory Committee for Aeronautics for their cooperation. Thanks are also due to my brother, Donald R. Black.

References

(1) Heat Balance Tests on Automobile Engines by Fishleigh and Leigh. *S. A. E. Transactions*, 1917, part 1

(2) Notes on Radiators for Airplanes by J. C. Hunsaker. *Aerial Age*, May 29, 1916

(3) Automobile Engine Cooling by Schanze. *S. A. E. Transactions*, 1917, part 2

(4) Aviation Engine Development by Sherbondy. *S. A. E. Transactions*, 1917, part 2

(5) The Cylinder Cooling of Internal-Combustion Engines by Lanchester. *Proceedings Institution of Automobile Engineers*, vol. 10

(6) The Flying Machine from an Engineering Standpoint—Motive Power Installation by Lanchester. *Proceedings Institution of Civil Engineers*, vol. CXCVIII

(7) Comments on the Effect of Size on the Thermal Efficiency of Motors by Lanchester. *Proceedings Institution of Automobile Engineers*, vol. 1

(8) Surface Cooling and Skin Friction by Lanchester. Report of British Advisory Committee for Aeronautics, 1912-13

(9)[2] Notes on British Radiator Report on Royal Aircraft Factory and Admiralty Tests. U. S. Navy Aircraft Technical Note No. 13

(10)[2] Notes on Eiffel's Radiator Tests, July 12, 1917. U. S. Navy Aircraft Technical Note No. 14

(11)[2] Experiments on Aeroplane Radiators by the Eiffel Laboratory, September-October, 1917. U. S. Navy Aircraft Technical Note No. 28

(12)[2] Section Technique Aeronautique Radiator Tests. *Bulletin of the Experimental Department, Airplane Engineering Division*, U. S. Army, June, 1918

(13)[2] Review of British Radiator Tests. *Bulletin of the Experimental Department, Airplane Engineering Division*, U. S. Army, October, 1918

[2]Confidential. The majority of the confidential references given are available to engineers of U. S. Government aircraft contractors.

Digitized by Google

(14)[2] Liberty Engine Heat Balance. *Bulletin of the Experimental Department, Airplane Engineering Division*, U. S. Army, June, 1918

(15) Engine and Radiator Data by Klemin and Huff. *Aviation and Aeronautical Engineering*, April 1, 1917

(16) Aeronautical Engineering and Airplane Design, Part II, Chapter 4 by Klemin. Published by the Gardner Moffat Co., 1918

(17) Handbuch fur Flugzeugkonstrukteure by Haffner

(18) Disturbing Bodies on Wing Surfaces by Klemin. *Aviation and Aeronautical Engineering*, Aug. 15, 1917

(19) Report on the Halberstadt Fighter. Technical Department, Aircraft Production, British Ministry of Munitions. Reprinted in *Aeronautics*, Oct. 9, 1918

(20) General Specification for Airplanes, No. 100-A. issued by the Bureau of Construction and Repair, U. S. Navy

(21)[2] Handbook of Instructions issued by the technical department, British Ministry of Munitions and reprinted by the technical section, Department of Military Aeronautics, U. S. Army, Dayton, Ohio

(22) Heat Distribution in an Aircraft Engine. Report No. 146 of the United States National Advisory Committee for Aeronautics

(23) General Analysis of Airplane Radiator Problems. Report No. 59 of the United States National Advisory Committee for Aeronautics

(24) General Discussion of Test Methods for Radiators. Report No. 60 of the United States National Advisory Committee for Aeronautics

(25) Head Resistance Due to Radiators. Report No. 61 of the United States National Advisory Committee for Aeronautics

(26) Effect of Altitude on Radiator Performance. Report No. 62 of the United States National Advisory Committee for Aeronautics

(27) Water Flow Through Radiators. Report No. 63 of the United States National Advisory Committee for Aeronautics

(28) Airplane Radiator Construction by P. M. Heldt. *Automobile* and *Automotive Industries*, Sept. 20, 1917

(29) The Gallay Radiators. *Aerial Age*, Sept. 3, 1917

Digitized by Google

(30) Aircraft Radiator Hose Specification No. 16026 issued by the Bureau of Aircraft Production of the U. S. Army

(31)[2] Radiator Design Booklet issued by the technical department, aircraft production, British Ministry of Munitions, Publication C. I. M., No. 726, Aug., 1918

(32) Experiments on Heat Dissipation. *Automotive Industries*, Sept. 19, 1918

(33) Transmission of Heat from Solid to Air Passing through Ducts or Pipes. Snyder, Robinson and Richards, *Journal Industrial and Engineering Chemistry*, June, 1916

(34) Effect of Altitude on the Horsepower of a Gasoline Engine. S. A. E. Data Sheet No. 52a

(35) Wind Resistance of a Radiator of Honeycomb Type. National Advisory Committee for Aeronautics (British) Report 1910-11

(36) The Effect of Size on the Thermal Efficiency of Motors by H. L. Callendar. *Proceedings Institution of Automobile Engineers*, 1906-7

(37) The Sylphon Motor Thermostat. *Aviation and Aeronautical Engineers*, Sept. 15, 1917

(38) Effect of Altitude Upon Boiling Point of Water and Atmospheric Pressure. S. A. E. Data Sheet No. 52

(39) National Physical Laboratory photographs of air flow around streamline, etc. Reports of British Advisory Committee for Aeronautics 1911-12 and 1912-13

(40) Report on Gotha Bomber with Notes on Giant Aeroplanes. Technical department, British Ministry of Munitions, 1918

(41) Radiators for Airplane Engines. *Aviation and Aeronautical Engineering*, Dec. 15, 1917

(42)[2] Resistance and Cooling Power of Eight-Side Type Radiators. Wind-tunnel Report No. 80, Washington Navy Yard, 1918

(43) Tests of Airplane Radiators by P. M. Heldt. *Automotive Industries*, Feb. 27, 1919

Note: There are also a considerable number of foreign reports available to engineers connected directly with the U. S. Army and Navy.

Digitized by Google

NAVAL AIRSHIPS

By Commander J C Hunsaker,[1] U S N

THE design and construction of airships in the United States was inaugurated by the Navy in 1917, with the B class of sixteen small airships. These were built for training and coast patrol. They were used to train 150 pilots and covered 140,000 miles of patrol without loss of life. The following year the C class of twice the size was brought out and proved very successful. The development of airship construction has progressed rapidly, but because of such a delayed beginning, the United States is still very far behind England and Germany. In particular, the large rigid airships of the Zeppelin type have not yet been attempted here, but their use during the war by the German navy, as scouts over the North Sea, indicates that they are necessary to a modern fleet. A short account is given of the German North Sea air organization, showing the seaplane bases laid out to cooperate with the airships.

It has been very gratifying to all of us, especially to our own builders and manufacturers, to learn by an inspection of what the French, Italians, English and Germans have done, that we are superior to any of them in workmanship and care in the handling of materials. In design we are certainly on a par. In some types we are superior to them; in others we are not. It is a fair average. Glenn Curtiss is the father of the flying-boat, and both he and we are glad to know that the flying-boat is still an American institution.

In connection with lighter-than-air craft, we have always lagged behind and are still behind, but we made a late start. For example, in the care of free balloons and the early dirigibles, the experimental work and the pioneering were all confined to France. The French two generations ago had worked out the complete theory of design and operation for these types. They knew all about them before there were gasoline engines to put into

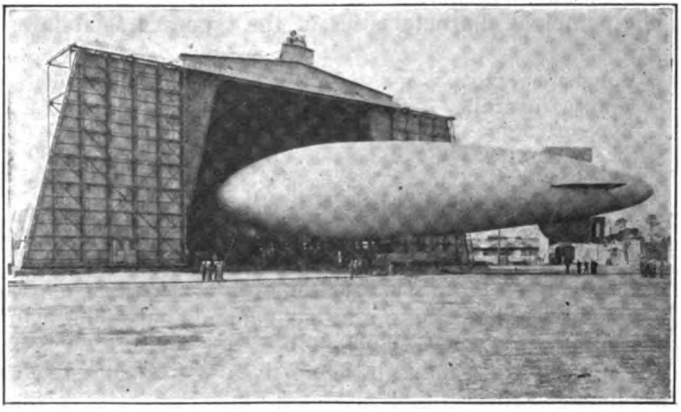
[1]Bureau of Construction and Repair, Navy Department, Washington.

Digitized by Google

the airships to make flight at all useful. The Germans started with airship work about 1895; the Italians somewhat later; the English, I think, made no serious effort until about 1911 and 1912. The United States began in earnest in 1917. Following the example of our English friends who have quite caught up from the time they have been at it, we ought to be able to catch up very shortly, if Congress will vote the necessary funds.

Beginning of Airship Construction

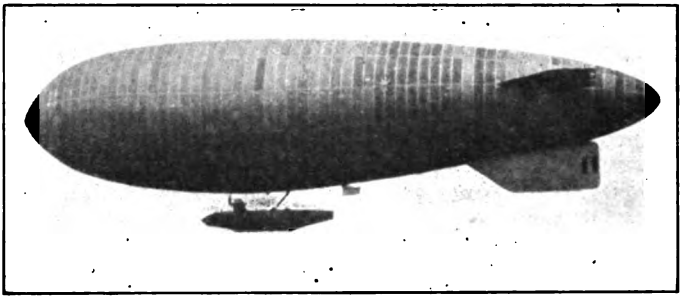
The first serious work with airships in the United States was done in 1917, when the Navy Department arranged for the construction of sixteen small ships.



Navy Training Airship Entering Hangar

They have been described as "blimps." I would like to correct one rather general impression that these ships were based on a foreign type. They were not, but were designed before the United States had gone into the war from a picture on the back of a postcard that was smuggled out of England, and from an account by a returned traveler who had seen something in England that he tried to describe. We had the information that the English were working on a certain small airship for a submarine scout and that the type was useful. We then started with the same general problem, and as very frequently happens, we came out with about the same result.

Digitized by Google



THE NAVY AIRSHIP C1 IN FLIGHT

As I have said, we built sixteen of these small ships. The principal characteristics of the type are as follows:

Volume, cu. ft.	84,000
Length (overall), ft.	164
Type of engine	Curtiss
Size of engine, hp.	100
Speed, miles per hr.	45
Range at full speed, miles	500

They are not remarkable for any great performance, but they have trained 150 pilots for us in the time we have had them working, and have done about 4000 hr. of patrolling, covering 140,000 miles.

Thus far there have been no lives lost as a result of accidents to these ships, although almost everything that could has happened to them. I think that is a very good record. We claim, of course, that the principal reason for the fine showing is that the ships were well built to begin with.

These ships have been doing regular submarine patrol work along Atlantic coastal waters throughout our period in the war, and have acted as convoys for whole fleets of merchant ships; they have really been useful for that limited function. They cannot go very far to sea because they have only one engine. We had one case where a few lads in one of them got caught out at sea and in a helpless condition drifted for two or three days and came down at Halifax. Their being saved was more good luck than good management, so we decided that we wanted two engines, and have brought out our second type with twin Hispano-Suiza engines. This is nearly twice the

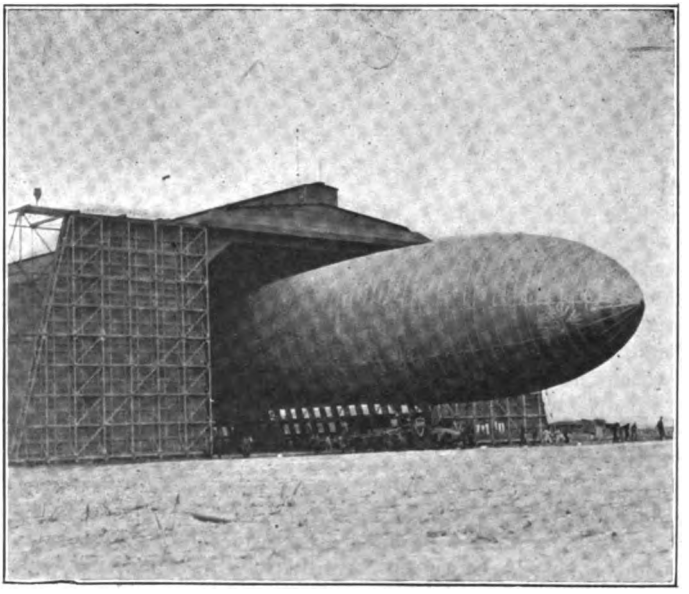
Digitized by Google

size of the first model and the speed was pushed up above 60 miles an hr., the radius being about the same. The ships with the twin engines are fairly new, but the first one of the series has flown from Akron to Washington, then to Rockaway, and now it has gone down from Rockaway to Key West. The longest flight was, I think, 30 hr. We are building about fifteen of them, and hope to make small changes from time to time to improve the general type.

For 1919 we shall bring out a new ship of an improved type, a little larger. It is naval tradition that the Bureau of Construction and Repair brings out a new "spring style" every year. We have not yet shown our style for this year, but shall do so shortly. I have been talking about last year's spring style.

These non-rigid airships can be built pretty rapidly, and as we know from our own experience, they are fairly safe. They are used principally for coast patrol and convoy work. Their duties are supplemental to the rapid and intensive surveillance of coastal waters by seaplanes.

We always want to be sure that we do not get into any



NAVY AIRSHIP C3 LEAVING HANGAR

Digitized by Google

argument with our heavier-than-air friends. There should be no argument. I once heard two men argue as to whether the mountains are better than the seashore. You cannot settle such questions by argument, nor can you settle by argument whether the seaplane is better than the dirigible. It all depends upon what you want them for.

The seaplanes watch the area within 100 miles of the coast and zig-zag back and forth over assigned sectors during daylight. The small airships proceed further out to sea beyond the range of seaplane patrols, to watch for submarines and enemy mine fields, but principally to accompany convoys of merchantmen. An airship can loaf along for a day or two with the convoy and not leave it to return to port until it is well out in the open sea and comparatively safe. This function of convoying ships out from our coastal waters is pretty well accomplished by our present types, but of course we shall keep on improving them. However, the amount of improvement that we can get is not very great. When we come to consider the fleet requirements for a strategic scout, we must have an airship with an endurance in the thousands rather than hundreds of miles. We have then got to think of the German Zeppelin. The Germans have developed just such a weapon, have taught us how it should be used and how it ought not to be used, and have very obligingly presented specimens of their work to the Allies from time to time, so that there are no longer any secrets about it.

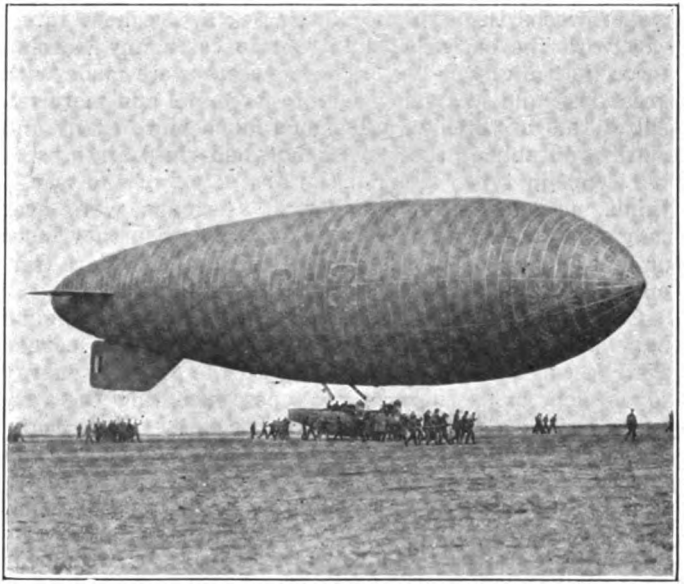
The Zeppelin

The black paint on the belly is put there for night work, so that the ship will not shine in the beams of a searchlight. The top of the ship is left white, so that some light will come through the outer cover and illuminate the interior where men may be working. That particular type of ship is intermediate between those with which the Germans started the war and those with which they finished. It is about 2,000,000 ft. and plenty large enough to cross the Atlantic and get back again, in good weather.

The Germans had a considerable fleet of Zeppelins available at all times during the war, in spite of such losses as they are known to have suffered from attempting to bomb towns in England. Admiral Jellicoe has just written a book in which he discusses his handling of the Grand Fleet during the first 2 yr. of the war, and in it

Digitized by Google

he states very clearly that the Germans enjoyed a distinct advantage over him, due to their possession of Zeppelin scouts. He mentioned one specific instance when a cruiser force was sent out from Harwich to make a sweep down the North Sea and was embarrassed by being



NAVY AIRSHIP C3 ON THE FLYING FIELD

tagged by a Zeppelin throughout the entire period of daylight. The commodore of the cruiser force could merely report that he found no German ships at large on the North Sea and that he was watched by this Zeppelin all day.

On another occasion the entire Grand Fleet was out with all forces, destroyers and light cruisers, battle cruisers, battleships, etc., and made a wide sweep down the whole length of the North Sea. On that day the Germans had ten Zeppelins out, which stretched in a line across the North Sea. The Fleet, of course, found no Germans on the water.

This matter of sweeping the North Sea was the principal occupation of the Grand Fleet. In addition to having to restrain the German High Seas Fleet, the British

Digitized by Google

had to maintain an effective blockade, to deny access to the Atlantic steamer lanes to German commerce raiders, and to protect the British coast from raids by German cruisers. All this was done in spite of German submarines. It was not possible for the British to maintain Farragut's type of blockade, because the submarines would have got them. It therefore became the policy to make sweeps through the North Sea at frequent intervals with the entire Grand Fleet to catch any German force that might be out. These sweeps were made with great risk and wear-and-tear on personnel and material. All of this might have been done much more easily and more profitably if the British had had rigid airships of the Zeppelin type. During the first 2 yr. of the war, I think, no substantial number of Germans were ever caught out, except at Dogger Bank, and then they more or less all got back. Then came Jutland, and more Germans got back than should have, even there.

Considering the problem of the North Sea, the English have had some years to study that and have now learned their lesson and are proceeding with the greatest energy to develop an air fleet of all types, including the very largest rigid airships, as part of the fleet. They began at the beginning of the war, had many disappointments and considerable success, and, assisted by the Germans' example, as they have been, are now building ships that are the equal of the Germans' in performance.

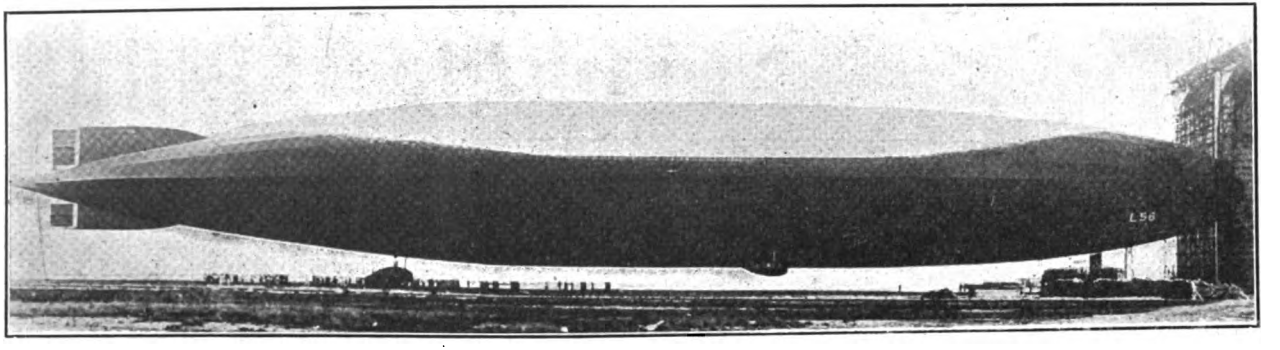
The United States Navy has not yet started on this kind of building, but when we do our engineers and manufacturers will have the benefit of all this German and English experience, and I, for one, have no doubt what the result will be.

Zeppelin L64 is about 2,000,000 cu. ft., which means that its lift is 61 tons. The useful part of this is 33 tons, that is, over 50 per cent. These ships will carry over 55 per cent and the larger types 60 per cent of their total capacity as useful load. The speed of the last ship was 77 miles, which may, I think, be increased to something above 80 miles by improvement in the powerplant.

We have learned something interesting about German engines. We have thought all along there was mystery about the power the Germans were getting, and it has now come out that they were rating some of their engines at 3000-m. altitude. So you see that they were not getting something for nothing.

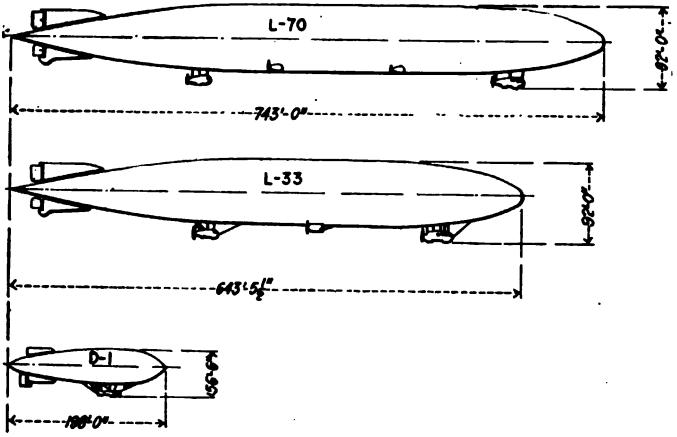
The diagram shows about where the United States

Digitized by Google



AN EARLY TYPE OF ZEPPELIN

Digitized by Google



RELATIVE SIZE OF GERMAN AND AMERICAN AIRSHIPS

stands. The little ship at the bottom is our big non-rigid airship that we talk about so proudly, and L-33, the middle one, is the German ship of 1916; the top one, L-70, is the German ship of 1918. It seems to be up to us to take another step.

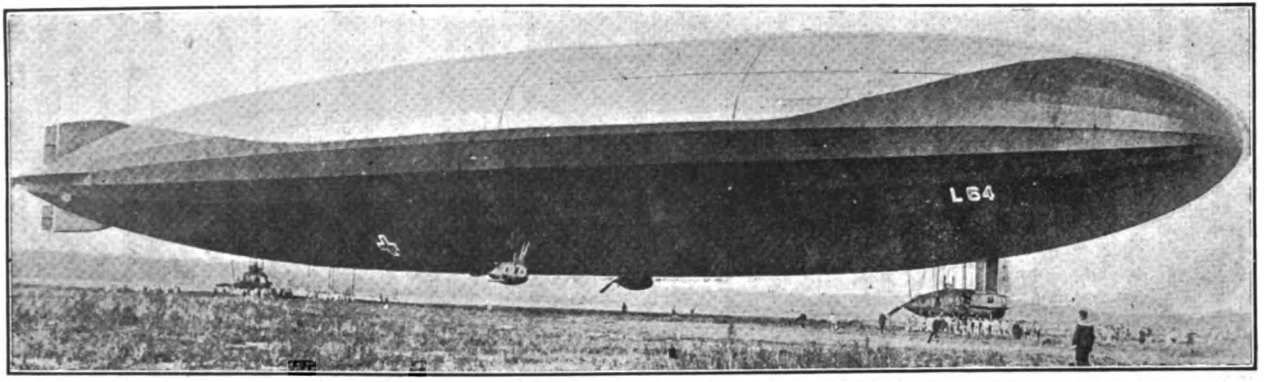
The tracks that are drawn on the map of the North Sea indicate the routine patrols of the Zeppelin airships up to the coast of Norway and back again, and out beyond the Dogger Bank and back. These patrol lines watched the movements of British ships approaching German waters. In addition to all this there were extraordinary patrols and bombing raids, and all sorts of things that are not shown on the map.

WHAT THE GERMANS CAN TEACH US

We can learn much from the Germans, and we will have to accept their competence in engineering matters, and even more in their organization than in their engineering. There is no time for me to talk now about the engineering problems in the design and development of the Zeppelin, but it is a very beautiful job, and it has been worked out logically and thoroughly. The designer almost speaks through it; you can see why he altered the construction from year to year.

The Germans concentrated all of the modern and working part of the entire Zeppelin fleet at three stations: Witmundshaven, Nordholtz and Alhorn. They had an-

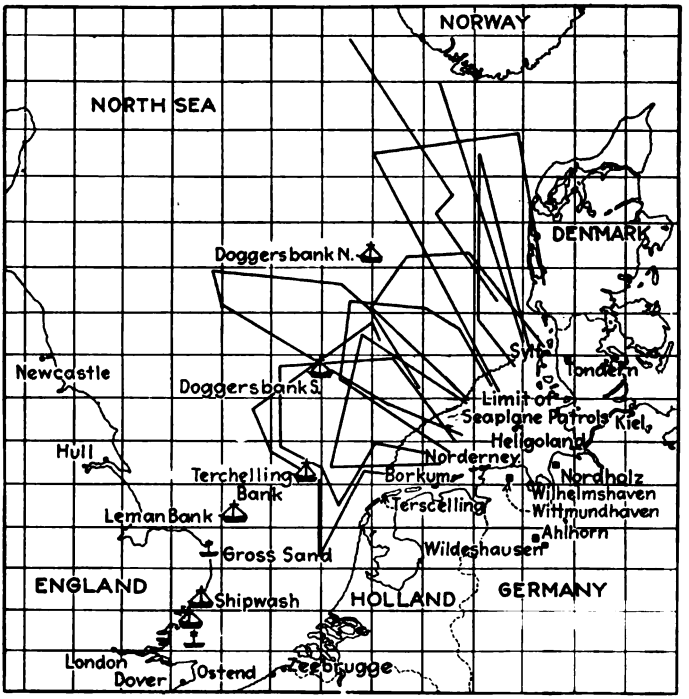
Digitized by Google



A Recent Zeppelin Having a 61-Ton Lift, of Which Over 50 Per Cent Is Available for Load Carrying

Digitized by Google

other station up at Tondern, but neglected to protect it properly with airplanes. The result was that a British man-of-war came in, launched some seaplanes with bombs and blew it up. To protect the three remaining stations from raids such as occurred at Tondern, they had the airship patrols which covered the North Sea. These gave them warning many hours in advance that naval forces were approaching. Behind the wavy line is the seaplane patrol. The seaplane stations were placed on the islands of Heligoland, Borkum and Nordholtz. Those



ROUTINE AIRSHIP AND SEAPLANE PATROLS MAINTAINED BY GERMANY IN THE WAR

stations maintained modern seaplanes of both patrol and fighting types, and the area inside of the jagged line was under constant scrutiny in the daytime. In addition to that, fighting seaplanes with machine-guns, two ahead and one behind, were always ready to take the air on instant notice. These were lined up in the hangars

Digitized by Google

ready for immediate use. However, the Allies never attempted to make a raid on the German naval bases. It might have been very embarrassing for the English to make a long flight across the North Sea and then run into a hornet's nest of fighting planes. These planes were kept in steamheated hangars, fully warmed up. It was a lesson to me that steam heat was a military factor in airplane design. At one station there were ninety-eight new planes lined up, ready to start out.

In addition to this seaplane protection, the patrol and the fighters at each of the Zeppelin stations, was a squadron of land planes, in command of an army officer detailed to the naval air station. These planes were ordinary single-seater fighters, kept ready to take the air on receipt of an alarm from the seaplane stations.

On the matter of Zeppelin vulnerability, we were able to get certain statistics which appear to show that the Germans have lost about 50 per cent of their ships by fire, started either by accident or as the result of explosive bullets. Taking the same chances with the weather as the Germans, if we can substitute a non-inflammable gas, such as helium, for hydrogen, we should save 50 per cent of their losses. We ought to save all the fire losses. The United States is in a commanding position, having the only known available supply of helium. We should forge ahead and make use of this asset by building ships of the Zeppelin type to be filled with helium. Learning to operate will be much cheaper for us, since we shall not burn up the first few ships. The production of helium is an assured success, and if we can lift and float our fine constructive work with helium, I think the country will be well satisfied with the record we shall make.

Digitized by Google

ADDRESSES AT THE HOME COMING SUPPER

The afternoon technical session of the Society held at the Hotel Morrison, Chicago, Ill., Jan. 30, was followed by what was termed a Home Coming Supper. About 400 members and guests representing various automotive industries were present. The speakers of the evening included H. H. Merrick, president Chicago Association of Commerce; Col. Chauncey B. Baker, motor transport section, Quartermaster Department, and President Kettering. E. E. Peake, executive secretary, National Automobile Dealers' Association, acted as toastmaster.

ADDRESS OF E E PEAKE

The automotive industry, which is yours, has just slipped in on us. It is getting bigger and bigger, and I think we who are interested in it scarcely realize as yet the magnitude of it or what it is going to mean. It is my belief that the invention of the automotive powerplant marks this as one of the really big creative periods of the world. Self-moving vehicles, in the air as well as on land, will undertake all kinds of transportation. In 25 yr. from now there will be permanent highways throughout the country, electric-lighted, and of course, policed. There will be the farm houses all along these roads, electrically lighted. Every farmer will have an automobile and few will have a horse. There will be union freight stations for truck haulage. Chicago will have one three times as large as any such freight station now in the world. There will be passenger stations also.

Just now we are all talking about reconstruction. We don't know much about it and several of us hardly know what it means, but I for one think it is fine. I have fallen into the habit of using the word along with camouflage and fuselage, words that we like to say, but to be serious for a moment, the length of time needed for reconstruction will be measured by the use the business world makes of the car, the truck, the tractor and the airplane in bringing life back to normal conditions. Business in this country cannot walk. It cannot follow a

Digitized by Google

horse. It must go on wheels propelled by engines, and I am sure that we shall all watch and work for results. Those who are in the business need no encouragement to push their particular work.

ADDRESS OF H H MERRICK

The things accomplished by the men of your profession and by this splendid organization during the war are well known. When the history of this war is written the Society's deeds will appear in glowing words. I know something of the proportion of your men who have given of their time and service, brain and effort, to war work. When, perhaps during our generation, the causes of this war, the reasons that led up to it, the history of the war itself and the analysis of those things that made for the winning of it by the Allies shall all be set down, we shall find that full credit is given to what I consider the fundamental reasons for our success—the wonderful spirit of America, the spirit of sacrifice, of willingness to serve, of readiness to do whatever seems the best thing to do. The breaking of the morale of the Germans was not due alone to the magnificent valor of the men in the armies of the Allies and our boys, but to the sudden, complete realization that our nation over here had only begun to fight; that the civilians back here, 107,000,000 of them, were approximating an efficiency never before known in the world; that great fleets of airplanes for which you men were chiefly responsible would in a short time be ample to wipe Germany from the face of the map; that our tremendous production of trucks and of foods, the cereals and fruits of the soil, made it humanly impossible for any end to come save victory, as our flag went forward.

It is said that republics are ungrateful; that things are soon forgotten. One of the chief industries of today in our United States is known as the investigating committee. I happen to be before one at this time, temporarily relieved that I may address you, and week by week, and month by month we shall hear of these investigating committees made up of Congressmen, going about looking into causes of "the death of the horse that died last year," instead of considering the ones that should lead to our prosperity in the future, and the country-wide problems that lie ahead.

Digitized by Google

I have watched you men through the war. You have been regulated; you have had to shut down because of war needs. You responded well, turned from the manufacture of passenger cars to trucks, to airplanes or airplane parts, and there was not a murmur. You have swung back more quickly than others from war to peace, you have a cheer on your lips and you are here in convention! That is the spirit of America, the spirit of which we are all proud.

Now let us drive this nation ahead as it has never been driven. As for the politician who wastes time in investigating the horse that is dead, let us scrap him as we scrap a machine that is worthless and a liability. Let us get rid of some of our dead wood and put in live men. Let us do the thing that we think is right and we shall have such business prosperity and success as we have never had before. Incidentally, we shall do more for the rest of the world than if we study the theories of Herbert Spencer or the economic dreams of the sages. The ideals of 2000 yr. ago and the ethics of by-gone ages do not fit the situation. Let us do the thing that lies before us without hindrance from any man or nation. Let us talk what we believe. No man can tell us to stop today in these United States. The war is over!

ADDRESS OF COL CHAUNCEY B BAKER

At the risk of boring you, I am going back just a little into the history of the motor car in the Army. It was a long time in gaining recognition. There were reasons back of this that I perhaps would not be applauded for stating. The first automobile that saw service in the Army in an official way came along in 1903. I remember it very well. It was brought out in exhibition at one of the annual encampments we were just commencing to have in those days and a distinguished officer was to catch a train in it at a station not so very many miles away. He started, but did not get the train until the next day.

That little thing queered the automobile game with all those who witnessed the trial. I am citing this merely to show you how very young you all are. Little was done in that way for a year or two, but in 1906 the first unit of the Army was equipped with automobile service.

Digitized by Google

This happened to be the headquarters of the army of pacification that went to Havana in the autumn of 1906.

In those days great armies did not go abroad as they have done recently, and six automobiles were enough to equip the headquarters of that small body of troops. They were of various makes, and were very effective, lasting to the end, the entire 2½ yr. that we occupied that country. This will give you an idea of the great strides that had been made in 3 yr.

From that time on the automobile was a fixture in the Army so far as it was possible to induce the Congress to furnish funds. That was not easy. I had some experience in that line myself. The first motor truck to be used in the Army was purchased in June, 1907. It was sent to one of the depots and was so frequently out of repair that it was not looked upon with great favor. The next year one or two more were procured. It was not until 1912, however, that those high in authority became convinced that the motor truck could really take the place of the Army mule. From that time on the movement was very rapid. In 1912 a run of motor trucks was made through a very difficult part of our country and they all came through the test, though some of them had had more or less assistance. All of them were met at every stopping place with a multitude of spare parts, and the whole course was laid out so as to afford opportunities to repair the trucks as the parts broke, showed wear or got out of order in any way.

By the end of that fiscal year, June 30, 1913, the feeling had become very general that what we needed was the motor truck. We needed a stout one that would go where any ordinary form of transportation could go. We always had to have assistance, however, when we got close up to the troops, and it never came to be the belief of the Army men that the Army mule could actually be replaced by machines. It is not the general belief yet except in places where the troops themselves are tied to the ground, as in the trenches, or localized. When on the move across country, over fields, ditches, woods and everything else, the animal transport of the regimental organizations has still been maintained, not only in our own Army but in all other armies.

On June 30, 1913, the total number of trucks for which funds had been provided, the appropriations of Congress at that time were made so that if it stipulated money should be spent for matches it could not be spent

Digitized by Google

for candles, was six in the United States and one in the Philippine Islands. However, by a strong presentation to Congress we were able to do much better from that time on, and gradually the number in use in the Army and other places increased rapidly.

At the beginning of the last Mexican trouble, when we went over the border after Villa, we had more than thirty different makes of truck in use. That may seem like a departure from any scheme of standardization but as a matter of fact it was in pursuit of standardization that this very considerable number of trucks was introduced into the military service, the object of it being to test out weaknesses and correct them; to give the makers and the engineers the opportunity to correct errors. Certainly the work that we gave those trucks on the Mexican border, and later on over the border in Mexico, disclosed whatever weak spots there were.

At the time the expedition started from the Mexican border after Villa this large number of trucks was distributed among the Army depots, military posts and large stations, with a number along the border, but there were not enough of any one kind anywhere to be organized into a body.

There was no truck organization except on paper. The draft was first put on paper in 1912 but was not accepted by the War Department until more than 3 yr. afterward. When Villa entered Columbus and shot-up the town, troops started to the south, and it was obvious at once that some means other than mule trains would have to be provided to supply the troops that were to follow him into the interior of Mexico.

This had all been foreseen by those whose business it is to watch these things, and although no funds had been appropriated arrangements had been made with manufacturers who were able to put the organizations together in the form of truck companies, which, however, were not yet recognized by the Department. They were able to furnish not only the material but the men. In those days our organization provided for no enlisted strength and for no commissioned strength, primarily because we had no trucks, but we had the paper organization and this was placed in the hands of these people. They selected for us men who were, for the most part, particularly intelligent, those in charge being exceptionally so, and they were so prompt in turning out equipped units manned with trained men, that in one instance the

Digitized by Google

officer who was to take command of a company in Chicago failed to arrive in time. Within 48 hr. or a little more the company had reached the Mexican border by rail, was immediately unloaded and was able to deliver stores to the troops in Mexico, over no roads at all, before the troops were out of rations.

One after the other the truck companies were put on the line and extended at the maximum rate, almost 500 miles below the Mexican border, over a country that was absolutely roadless for more than half of the way and mere mountain trails the rest of the way. That continued until the expedition of 10,000 men was finally brought out of Mexico.

You are all familiar with the splendid purpose of your Society and the help it gave to the Government in producing a standard truck that could be used anywhere and would find its parts wherever you could take it. In every machine shop you would find the parts to repair it, made by a sufficient number of manufacturers, so that there would never be any question as to the practicability of the Government's procuring them, and let me tell you what led incidentally to the belief that this was a necessary part of the equipment of the Army. In 1898, as you know, we were at war with Spain and the Army was equipped with mule wagons manufactured by every maker in the United States. We had a standard at that time but no manufacturer was willing to follow it. He did not have the right material for it, there was not the time to do it, and he turned out and the Government accepted the particular wagon that he was making. As a result, in the particular corps I was attached to, we received some nine or ten different makes of these wagons. We would ask for spare parts, and get them for probably nine or ten other makes of wagon. The storekeepers were not familiar with the parts themselves and good as their intentions were, they would send down the wrong ones if they did not happen to have those that we had specifically asked for. They thought something else might answer the purpose. It did not. What we did then was to go into the swamps, cut green timber and construct what we actually needed to keep our wagons in repair. It served very well and results were good, but it is not always possible to find green timber and it will not repair motor trucks.

When our truck plan was started the War Department undertook correspondence with the various manufactur-

Digitized by Google

ers and users, and especially with your Society, and finally developed the standard truck. I do not know how to express to you our appreciation of the manner in which the members of this Society gave the very best of their lifetime of effort to the development of the best truck that they knew how to make. They came at the call of the Government and laid upon the table the most precious products of their brains, and these were welded into that standard truck.

It was claimed, in the first place, that it would not be possible to do it. Great Britain had failed, France had failed. It was maintained that there would not be sufficient time, that no truck had ever been produced in less than from 1 to 2½ yr. and that, in any event, it would be an experiment.

This is what happened: England had failed. I saw her failure myself on a visit to her factories. France had failed before making a real effort. Those two countries are not supplied with the standard machines that are used in all of our manufactories. They use a tremendously larger amount of handwork in both those countries and that is one of the reasons they not only did not succeed but did not feel the same necessity for succeeding.

The decision was made to enter upon this project late in July. By Sept. 10 the drawings for the truck were 90 per cent completed, a month later the first truck was practically completed and by Oct. 19 the first standard trucks had reached Washington and were turned over to the Secretary of War and later to the President, 69 days after the order to go ahead had been given.

By Jan. 10 the first commercial trucks were coming through and at the end of April they were coming at the rate of eighty a day. There never was a time after delivery once started that there were not trucks on the docks at the Atlantic Ocean, waiting to be sent overseas. In other words, trucks were coming through faster than it was possible to take them over.

That is what your Society—because the members of your Society are the people who are responsible for that product and you are the people who made it possible for the Government to do that thing—has done, and, as I started in to say, the Government has nothing but thanks for you for your effort, not only in this specific case but in other cases. When the history of the war comes to be written there may be some question as to who started

Digitized by Google

the war, but there will never be any doubt as to who ended it. This Society and its members, not only those shown upon the service flag that hangs in front of us, but those who remained in the factories and did the work that had to be done, will have their full share of credit. When the flag of our country has been borne upon a staff tilted toward the enemy, it never yet has tilted the other way until victory has been won. In this victory you know that you have had your full share. There are those who are represented by stars on the service flag. There are members of this Society who are represented in stars of gold. May their memory shine forever. But remember that those of you who may not be represented upon that service flag may still, I beg of you, allow that we who wear the cloth may call you our next of kin.

ADDRESS BY CHARLES F KETTERING

Out of the great experience of the past year and a half we have gained one very interesting thing from the standpoint of the engineer. Into a great common pot has been dumped the technical information and engineering skill of all the industries. We have now at hand, as we never had before, a mass of technical information that is going to be of great avail. Next year we shall suffer from so-called reconstruction, but out of it there will come industrial development which will so far surpass the things we are familiar with, that we shall more than make up the losses we have had during the wartime period.

The demand for engineering work, the pressure of commercialism, may drag the engineer a little faster than he can step, if he does not avail himself of this information which has been so generously given. The problems that commercialism is forcing upon us will keep us running unless we grasp the situation, analyze its factors and work together. Now is the time for us to card index for quick reference all this wonderful information which we have got during the war.

Along with our aeronautical development have come a few things of scientific interest that I want to mention. One is the contribution which science has made in the way of communication. As is well known to you, our American planes are equipped with a radio telephone so that it is possible for a man in the air to communicate with his fellow pilots in the air or with headquarters on

Digitized by Google

the ground. All of that development is going to be carried over from aeronautics into other things. Out of this development of radio has come a very interesting thing, as applied to our long-distance telephone work. Radio, as you know, emanates in a spherical method; that is, it gives out waves which go in all directions. It used to be necessary to have rather high-powered stations to receive and to send, but it is not now. It would be possible tonight for us to take two little card holders, place them on the table here a few feet apart, string some connecting wire between them, put a magnifying device in place and listen to talk in Arlington. We could hear the battleships along the Atlantic coast talking to each other with that much of an antenna in this room. That has been made possible by our ability to magnify the radio signals. A little device which was developed and perfected during the war time can take an insignificant signal such as we would get over these wires and multiply it, by a single step, 1000 times. Then if we cannot hear it, multiply it 1000 times again, which gives 1,000,000 amplifications or by still another thousand and we get 1,000,000,000 amplifications. The chances are we can hear it by that time but such magnification can be kept up until the radio signals become perfectly definite.

There has been another type of radio developed which is of great commercial importance known as wired wireless. This means being able to send a wireless wave along a perfectly defined path and that defined path a wire. It is quite different all the same from passing an electric current through that wire. It differs in this way: If you are sending one electric current through a wire and try to send another through, there is more or less congestion at certain parts of the wire. With this wired wireless, however, it is possible to send one, two, three, four, six or ten waves simultaneously without any interference. Long-distance telephoning is being carried on today between Washington and some of the points where they are sending four simultaneous messages. This is possible by using a special frequency to call the other end of this line whether it be St. Louis or Kansas City, without interfering with important business which may be going over those wires at the same time. Another very interesting thing about that is that there is no distortion. The voice comes through clearly and plainly, even though it is traveling along accompanied by various other messages.

Digitized by Google

That is just one angle of the development that has come during our war. The same development can be applied to matters chemical and physical, and to engineering in every line. The engineer, if he is going to take his proper place in the next 5 or 10 yr., must learn more per cubic inch than he ever learned in his life before. He has got to be entirely awake. We are going to move rapidly; we shall see marked changes in every line of industry, because in every line there has been contributed new information and new things that a year or two ago we thought were impossible, if we thought of them at all.

Air travel will be made possible through this wireless communication that we have just discussed. There is one very fine thing about air travel, and that is that we can select the kind of weather we want. If it is raining in Chicago, as it almost always is, and we don't want to come to Chicago in a rain, we can just fly above it. I am not sure that the people of Chicago know that the sun shines above them, but it does. The only difficulty with flying above the clouds is to know where you are. Up there is about as lost a place as we can get into on earth. With little radio signals dotted down the line 25 miles apart and telephone receivers at his ears, the flyer could lie down, read or do anything he wished up in his airplane and still follow his course across the country.

Interesting things have been mentioned here tonight on the commercial side of flying, and the airplane is used as a synonym for speed. I want to use it as a symbol for many other things. The reason we go by airplane is that we want to get there in a hurry. I have used a plane commercially for the last year and a half. Colonel Baker and I came from the same school; were graduated in the same year. I happen to have to go over to that university once a month to attend a meeting of the board of trustees. It is about 75 miles from where I live to the city of Columbus. I have driven over there in 95 min. because a fellow was ahead of me and pulled all the cops off the road, but if I want to go over there as a high-grade, law-abiding citizen I have to take about 3 hr. to get there; to make a 10 a. m. meeting I must leave at 7 in the morning. If I go by airplane, I can wait until 9 o'clock or later. In fact, I can go from Dayton to Columbus as quickly as another member of our board can go in a street car from the Union Depot in Colum-

Digitized by Google

bus to the University. I can stay there until 3 o'clock and be back home at 3:30.

Such economy in speed is so fundamental that the aircraft industry will live regardless of what we think about it. We left Dayton at 11 a. m. and were in New York City at 3 p. m., 555 miles in 4 hr. As they have no regular place to land in New York City, we went 25 miles the other side of it to get down. We had sent telegrams to New York City, one ordering a taxicab to meet us at Mineola, another for rooms at the hotel and another for some theater tickets. We landed at Mineola and went into town, got to the hotel, cleaned up a little, took a nap, had dinner, went to a theater and were back in our rooms at 11 p. m. just 12 hr. after we left Dayton. The shortest time in which we could have made the trip by train is 18½ hr. That is a practical application of what can be done if conditions are right. There were a few places on that trip where if we had been compelled to come down, we would have had to juggle around a little bit, but then we would have come down, no question about that.

When we get this radio-marking across the country, it will be possible to take an airplane equipped with some new compass devices we already have and some other little trinkets that were developed during the war, put it on a course from Chicago to Dayton, and turn the flying of it over to the compass, which will do it better than we could anyway. I will guarantee that without touching the machine it will not miss the city of Dayton by 10 miles. We have done some things along that line, and since they cannot be denied, the sort of thing we hear about aircraft being unstable and fickle sounds ridiculous. We have flown from Dayton to Indianapolis without touching the controls, missing the center of the city by less than 1 mile; also from Dayton to Columbus without touching the controls, missing the city by less than ½ mile. There is no reason why we could not fly to Kansas City if we had to.

I am talking of the aircraft business because it is typical. The automobile, the tractor, the truck, every division of automotive engineering that has had or promises to have development equally great, has struggled with problems of equal importance. We have before us fuel problems. We have a lot of problems that must be solved by coupling together all the engineering knowledge available and directing it along a particular line.

Digitized by Google

Nobody is satisfied with the way an automobile runs today, because of the fuel supplied.

It is pretty definitely settled that we are going to accept just exactly what we get in the way of fuels, and I would say in defense of the oil companies that they are giving us the best they can. We can quarrel about the fuel all we want to, or design engines and equipment that will handle the fuel we get. When we have the problem solved we will wonder why we ever worried about it. The man who has wire fences on his farm is not troubled about the shortage of timber for fence rails. We shall not kick about the quality of our fuel when the engines are once developed that will handle any kind of fuel. It is no longer a problem; it is right in front of us today, with a dozen other things that we have got to do.

New materials have been brought out during the war that are going to affect all sorts of design in just exactly the way that high-speed steel affected the machinery industry. The introduction of this new steel into the cutting tools of our machinery has entirely revolutionized machine design. I can remember very distinctly when, not over 7 yr. ago, a machinery builder came into one of our plants, and, because of the failure of one of the tools to do what we had expected, said to me "If you take that fool high-speed steel out of there and put in ordinary steel you will have no trouble with the machine." That was absolutely true, but who wants to run his machines at half speed? That is what his suggestion meant, and the machinery people, after trying to convince us that we were running their machinery too fast, found out that neither of us could slow down.

It is well to remember that when an industry or a nation gets worked up to a certain speed, it is an awful thing to slow it down. We have learned things. We have gained the ability to do the trick of going ahead in the last year and a half, and nothing will slow us down. What is going to happen is that the fellow who believes we shall now slow down will himself in the end speed up to keep along with the procession.

Digitized by Google

CHICAGO MEETING PAPERS

ENGINE PERFORMANCE

By H L Horning[1]

EVERY plow in use should have 10 b.-hp. available. Every tractor engine should deliver continuously at least 33 hp. If the 330-cu. in. engine mentioned were as good as a Liberty airplane engine, it could deliver 57 hp. at 1000 r.p.m. The horsepower actually obtained is as follows:

41.5 in the laboratory
33.0 at the factory
29.0 when burning gasoline
23.0 when burning kerosene
21.0 with poor piston-rings
19.0 with poor spark-plugs
9.5 available at the drawbar

The great engineering problem of the future lies between the 57 and the 23 hp. From 19 to 9.5 hp. is the manufacturer's problem. The main difficulties, as outlined by the figures given, lie in the combustion chamber and its ability to dissipate the surplus heat, and in the limitations of fuel. There will be no need for refiners to continue to break up the heavier fuels by processes already so successful, if by ingenuity and good understanding of thermodynamics these can be made to burn in present-day engines.

I have recently had a very striking illustration of the losses that occur in engines from the time they are conceived in the engineer's mind until they actually commence to plow the soil. I have sketched here a typical case of a 330-cu. in. engine that I happen to know about, and have drawn it under different conditions so as to show what is lost, and also to trace and point out the problems of the different men who are interested, the engineer, the customer, and the service department. I have left out the manufacturing department which often takes a mean advantage of the engineer in the shop.

If this 330-cu. in. engine were as good as a Liberty airplane engine, it could deliver 57 hp. at 1000 r.p.m. In

[1]General manager and secretary, Waukesha Motor Co., Waukesha, Wis.

Digitized by Google

actual test the best we can get in the laboratory, with everything in fine condition, is 41.5 hp. That represents about 100 lb. mean effective pressure, which is about the best we can obtain from an engine with cast-iron cylinders and all the hindrances common to tractor engines.

The next figure is the best possible horsepower that a manufacturer can hope to get from his engine when it is ready to ship; 33 hp. is about the average when an engine goes out, 29 hp. is not uncommon with gasoline, 23 is a common output with kerosene, 21 with bad piston rings, 19 with bad spark-plugs and 9.5 is available at the drawbar.

This diagram shows at a glance the immense amount of work the engineer, the manufacturer and everyone concerned still has to do. The province of the engineer is from the 57 to the 23 hp. or the common output with kerosene, which is not good; within these limits lies the great engineering problem of the future. I know that a great many experiments are already being carried out to improve the compression at which engines can run on kerosene; the common tendency at the present time is to drop the compression to use the available fuels with their heavier constituents.

The problem from 19 to 9.5 hp. is that of the tractor manufacturer. It may hurt the feelings of some of them to use these figures, for a few can easily show 13 instead of 9 hp., but it is not uncommon to get down to the lower figure. As there should be 10 b.hp. for every plow used, it is realized what a difficult situation this is. What we really ought to have is an engine actually delivering 33 hp. all the time. Notwithstanding the many efforts that have been and are still being made by engineers to burn kerosene, it is my opinion, after years of work, that kerosene tractors are bought by the farmer to offset the possible robbery of high prices on the part of the oil interests. After they get their kerosene tractor they burn gasoline. I do not blame them after noticing the performances indicated on the diagram. It is not uncommon to drop from the 33 to 23 or even 10 hp. in the attempt to burn kerosene. It is my opinion, more from an engineering than from the user's point of view, that the user would be better off if he burned gasoline and kept the extra horsepower continually available.

With respect to the question of fuel, we are hearing and I presume that as the years go by we shall hear of

Digitized by Google

many new fuels. But there is a limit to all this. Engineers must come to the realization that the question is not one of producing an engine for a particular fuel; they must produce an engine for the fuels that are available on the market. The fuel we are to get in the future is not the fuel that oil men will want to make; it is the fuel they will really have to make, and it is an open question whether there will be enough to go around. That is the governing factor.

Another problem is the marketing conditions. One of the most satisfactory things about the present status in the gasoline industry is the fact that one can get gasoline almost anywhere. To build up the organization that provides our present distribution, the Standard Oil and the other oil companies have worked for years and expended millions of dollars. They must keep large reserves—sometimes $50,000,000 each—to meet the sudden demands for capital which occur when new fields are opened. It is capital, therefore, in the form of supply stations and organization for the distribution of fuel that will largely govern the types of fuel we are to have. That confines the engineer's problem to the task of building an engine that will burn any fuel, or fuel with a wide range of boiling points.

Using Different Fuels

I was recently greatly pleased to have a tractor manufacturer describe to me a heavy-fuel device which he had devised. By turning a lever he could vary the amount of heat applied to the incoming charge. On the lever was an indicator marked Gasoline, Distillate and Kerosene. It was very simple and appealed to me strongly. The tractor and possibly the truck of the future could be equipped with just such a device. Then when kerosene is needed all the driver will have to do is to turn the little knob marked Kerosene; if he wants to burn distillate, such as is found in California, which I presume will be available more and more in the East as we learn to burn it well, he will turn it on. When he must make use of high-priced gasoline he will have it at hand. That seems to me to be an important step forward. We should realize that we must deliver power irrespective of the fuel, a very hard condition to put upon engineers.

In the summer of 1915, during the last S. A. E. cruise up the Lakes from Detroit, I had a very pleas-

Digitized by Google

ant talk with President Kettering on the possible devices that could be worked out for catching the small variations in pressure inside of cylinders, and Mr. Kettering has since made an intense study of this problem. We have also done some similar work in our factory. It was through the suggestion and help of Mr. Kettering that we were able to produce a manograph which will allow us to spread the explosion curves out and produce a photograph in which 1 in. represents 0.001 sec.

It is fascinating to sit in the dark and watch the play of the curves as we burn kerosene, then inject water, and later vary the fuel to gasoline. There is a wealth of knowledge to be gained in this way which perhaps few engineers realize. If the engineer will stop long enough to adjust the carbureter and watch the various changes and curves, he will probably learn more than he could in years of field experience.

One of the interesting things we have learned is that the heavy-fuel knock which we all call "preignition," is really not preignition but after-ignition; it comes about 20 deg. after upper dead-center and is so sudden that the pressure rises to 900 lb. per sq. in. As a matter of fact, I have seen the pressure go up to 1300 lb. per sq. in. The light beam moved so fast that the photographic film failed to catch it. Those are real explosions. They take practically no time, so far as I can measure about 0.0002 sec., to run up from 150 or 200 to 1300 lb. The heat dissipation is very rapid and the pressure drops down to the previous point in the same short interval. Several such explosions occur one after another, showing that the cylinder is not doing good work; the fuel differs so much from the lower range up to the higher that we cannot produce conditions in the cylinder which will permit uniform and practical burning.

All this is interesting because the higher the atomic weight of the fuel and the heavier the kerosene, the more prone it is to break down under pressure. That is the law of explosives. If you want to have just a little night scene, light some powder on a table; the powder will blow up, but very mildly. Put a plate over it and you will have a little fun. Put a cast-iron casing around it and you will have to get behind the building. Put it in a chrome-nickel steel retainer and there will be music by the entire orchestra.

Digitized by Google

The pressure half of the compression and the first part of the burning of the fuel run the pressure in the cylinder so high that the unburned part of the fuel, that which has not yet ignited, is under very high compression and detonates. This has proved of practical interest, for if we are to burn kerosene and the heavier fuels in our present form of gasoline engine, we shall have to design a different type of combustion chamber to prevent these high pressures from getting to that part of the fuel which has not been burned. The ingenuity of some of the best engineers in Europe is now being applied to the solution of this problem, and I have no doubt that there will soon be marked advances along that line. It seems probable that one of the ways in which we can burn the heavier fuels will be by holding this terrific explosion wave or pressure back until we can feed the flame out gradually into the other part of the charge.

I hope that nobody will ask me anything more about this particular phase of combustion because I have told you all I know. I am very glad to have advanced thus far. I have made some experiments in the laboratory which give reason for hope. I recently met Mr. Stiger, and being a gasoline carbureter man, he said, "There is nothing in this kerosene movement; there is nothing to be gained from it." That may be the truth and a solution of the difficulty. As soon as we get a serious demand for gasoline the refiners may give us more and more gasoline out of the distillates and the heavier fuels, but it seems to me that the future will impose a very interesting problem upon our engineers. There will be no need for the refiners to break up the heavier fuels by processes already so successful if, by ingenuity and good understanding of thermodynamics, we can burn them directly in the engine. It would be a great mistake to spend money on fuel that could be saved.

In closing, I wish to call your attention as engineers to something that I observe nearly every day, either in our company or in others. The S. A. E. has among its members some very good engineers. History has been made by the work of these engineers and they are eminently capable of producing devices for the gasoline engine that are absolutely efficient. But this result does not always get through to the purchaser. Somewhere in between it is lost. First, they produce a beautiful design, but the factory changes the dimensions and off goes 10 per cent; then the superintendent takes 10 per cent

Digitized by Google

more; the chief inspector objects to fine dimensions and 10 per cent more is gone.

The engine is shipped out to the user. It is a new, raw engine and the man who has bought it has perhaps never run an engine before. It takes 3 or 4 months and sometimes a year for it to get down to smooth running. The first month is the worst, but if the owner gets through the first year he will not trade his engine for any other.

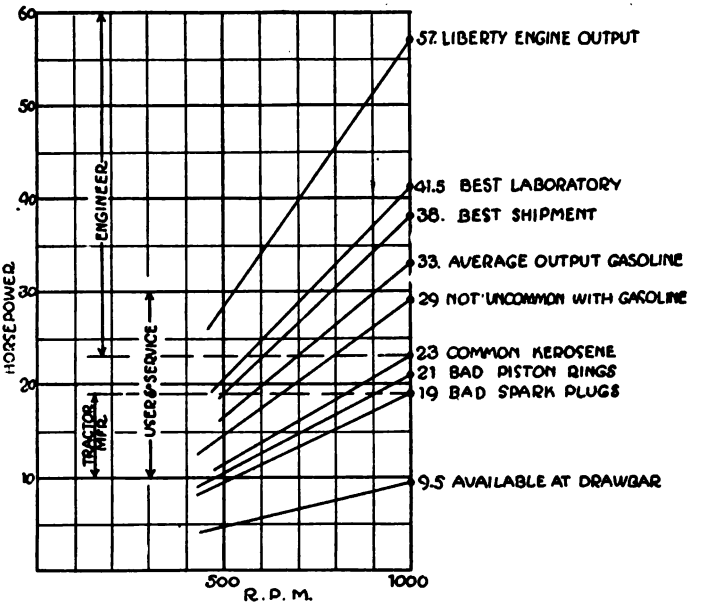


DIAGRAM OF THE POWER AVAILABLE IN A 60-HP. ENGINE WITH DIFFERENT FUELS AND THE VARIOUS PERSONS VITALLY INTERESTED

The engineer encounters another obstacle in the service department. I have sent service men to ten places recently where they were having trouble with our engines. There was not a man competent to give first aid in one of the ten places, although one station was a general agency and repair station for five states.

When you have a good thing, stick to it. If you are working on kerosene, for instance, do not give it up. We are running in a circle now. It is a bad time, but there is great hope. Those of you who have worked as I have for 3 yr., can spare time for night work in the laboratory,

Digitized by Google

trying to solve the problems of kerosene. Engineers who are willing to work, engineers who have produced the Liberty engine and all the other things that have made it possible for us to take Chateau-Thierry and start the war the other way, are bound to get somewhere.

THE DISCUSSION

C. E. SARGENT:—It occurred to me when Mr. Horning was giving us the points of disparity on this diagram, that there is an explanation for the trouble which he deplores. The Liberty engine, which is a poppet-valve engine, gives 57 hp., and the tractor engine only two-thirds of that, but there is really no difference in the thermodynamics. The pressure is the same and the speed can be made the same in both cases. I would like to ask Mr. Horning how he accounts for the discrepancy between a tractor engine giving its best horsepower and a Liberty engine giving its best horsepower. If I understand correctly what he has shown us, it does not seem that any comparison can be made between the two and I do not see what the mechanical differences are.

MR. HORNING:—The main differences lie in the combustion chamber and its ability to dissipate the surplus heat, and in the limitations of fuel. It is possible for them to carry compressions up to 140 lb. per sq. in. and I understand that with special fuels it is possible to carry these up to 250 lb. I also understand from Mr. Kettering that when they get up to 150-lb. compression the horsepower does not continue to increase. No doubt, as the radiation of heat varies as the fourth power of the absolute temperature and the specific heat of hot gases increases rapidly with temperature, the very high temperatures gained by the higher compressions are not available as power. For the truck we have an engine with the ordinary type of combustion chamber; it has a rough surface; it can be made in the overhead valve type with all the surfaces unfinished. It seems possible at the present time to get up to only about 100-lb. mean effective pressure, whereas the Liberty aviation engine will rise to perhaps 140 or 145-lb. mean effective pressure. I can see no other difference between them as far as the power of generation is concerned.

Of course, there is an element in a tractor engine which is very well taken care of in the aviation engine and that is the stiffness of the crankcase and the size of the crank-

Digitized by Google

shaft. Right there is a very interesting feature, which Mr. Milbrath has shown to good advantage in his paper. If I am not mistaken the connecting-rod bearing in the Liberty engine is 2⅝-in. diameter by 3¼ in. long, and in the Class B Government truck engine, around which Mr. Milbraith's designs are developed, the connecting-rod bearing is 2⅜ by 3 in. There is very little difference between the two and yet the output per cylinder is two and three times greater in the Liberty engine.

In the tractor engine the great value of crankshaft size is probably in the stiffness of the shaft. The engine must keep on working whether the bearings are taken up or not. It must meet the conditions of the farm whereas the Liberty engine in the hands of experienced mechanics, is taken down at regular intervals and the bearings if worn are thrown away, which is not true in tractor service.

The aviation engine has been brought to a very high state of efficiency as regards friction loss, a point that does not always have the necessary attention in the tractor engine. There is no doubt that the future holds great development in the line of horsepower, power that can be produced day-in and day-out, not the 41.5 but the 38 hp., regardless of conditions.

A very interesting thing happened in our experiments. I want to record it here, and perhaps start some good sport in a scientific line. While working in the dark with kerosene under very high compression, 90 lb. per sq. in., and the water discharge cut down so that the engine was sizzling hot and the radiator ready to burst, we were just about to take a photograph of the high pressures being developed, when suddenly a spark jumped from one side of the engine to another, a distance of some 20 in. It was an unexpected phenomenon and I immediately turned on the light to trace the source of the spark if possible. I found it started from the handle of the priming-cock and ended on some metallic object, I could not tell what. I have repeated that experiment many times and had 8 and 10-in. discharges from the priming-cock handle, always just at the time when we were getting the very highest pressure, 1300 lb., so high in fact that the copper tubing was ruptured and we had difficulty in holding the little aluminum mirror in the manograph to take the pressure. I have constructed several electrodes and placed them inside the combustion chamber to see if I could duplicate the phenomenon with an electrode of the proper shape to collect whatever charge there is. Thus far I have not suc-

Digitized by Google

ceeded. I have thought of a possible scientific explanation for the action but on such uncertain grounds that I take pleasure in laying the matter before you with the idea that there are some here who have studied deeper into the phenomena of ions than I, and may be able to give us some satisfactory explanation. Whether the burnt gases passing through the exhaust valve are charged with one sign of electricity, and whether, under the very high pressure and with the spark jumping in the combustion chamber, it is possible to collect a charge from the mixture and then dissipate it to the air along natural paths, are the questions to be answered. I shall be very glad to have the matter discussed either here or in writing. In it may lie one of the ways by which we can burn the heavier fuels. Perhaps, if we can get right after this charge which is disturbing conditions in the cylinder, we can burn our fuel in a much smoother and more perfect way. This is pure speculation, but I look forward with a great deal of pleasure to hearing from some of you on the subject.

CHARLES F. KETTERING:—Mr. Horning brought up a point or two on which I think I can throw a little light. The horsepower of aviation, truck and tractor high-duty engines needs to be given much consideration in the design. In the first place you cannot take an engine of 100 or 125-lb. compression and get 125-lb. mean effective pressure in it with any kind of fuel; it is fuel limitations rather than engine limitations that cause the difficulty. We built a Liberty engine of 210-lb. compression last year and ran it perfectly with explosion pressures no higher than with 100-lb. compression. This was done to ascertain if possible to what extent the fuel entered into the situation.

In the low-gravity fuels we have a type which breaks down into secondary compounds, some of which are highly detonating, and it is not an uncommon thing, as Mr. Horning has mentioned, to witness an extraordinary rise in explosion pressure. That pressure adds nothing to the energy of the engine; about the only thing it does is to put special duty on the bearings. You cannot run a Liberty airplane engine on ordinary gasoline, such as is used in automobiles, with a wide throttle, because you get bad hammering. For this 200-lb. engine we made up a fuel. You can build a fuel just as you do building blocks, using the ingredients in any way you wish. These made fuels did not behave badly. The explosion pressures were exactly the same whether we had 200 or 100-lb. compression

Digitized by Google

in the engine. That may seem mysterious but it really is not. If you have a fuel which will burn by a single step from carbon to carbon dioxide or from hydrogen to water the pressures can go no higher than the critical temperatures of the chemicals in combustion. You have a self-regulating fuel. The fuel we constructed for this very high compression has molecules of the same size. Any satisfactory fuel must have. The distillation curves, which are nothing but a manner of weighing molecules, must be closely studied.

Mr. Horning brought up the point that after you have run the compression above a certain point, you get no marked increase in horsepower. You should not expect it. About the only thing to be gained is a little better volumetric efficiency. So far as the explosion pressures are concerned, they are constant.

Here is an experiment that is worth trying. Take an engine of 75 or 100-lb. compression, put kerosene in it; and get it warm. It will hammer badly. Put 3 per cent of ethyl iodide in the kerosene, and even if you raise the compression of the engine to 125 lb. it will not knock. It will run just as smoothly on kerosene as on gasoline. The interesting question is: What does the ethyl iodide do? If some chemical reaction enters, what is it? We analyzed the situation, and found it simple. Iodine is a variable. Below 1200 deg. its vapor exists in molecular form; from 1200 on up to 2200 deg. it exists in atomic form. The energy required to change from molecular to atomic form just crushes off that critical temperature and prevents the formation of the secondary compound. If iodine did not cost so much it might be used to overcome the difficulty of burning kerosene. The number of British thermal units it takes to change iodine from molecular to atomic form is very small. Some one should work up or find a cheap substitute for it.

The knock which is heard in a cylinder running with a fuel that will crush without too great variation, at not much over the critical temperature, is not premature at all. It may come 5 or 10 deg. ahead of the top center or on the down stroke, more often the latter, since it takes a certain time to reach the specific heat of the gas and get up to the temperature where compounds begin to form. An analysis has shown us that the secondary compound which detonates and causes so much trouble is acetylene, one of the results of the combustion of a heavy molecule. If you pass kerosene through a

Digitized by Google

tube of iron filings you will generate a certain amount of acetylene. We put a spectroscope in the cylinder and got a strong carbon line on the spectrum every time. We went further with the experiment, and found that the carbon lens was illuminated just when we got the peak pressures.

In experimenting on these fuels we started with benzol as a base, because it seemed to be the most degenerate fuel we could get. It has gone through the acetylene stage, and in itself is not a very good fuel, for the reason that it is high in carbon, so we put in a certain amount of hydrogen. Such a fuel is more nearly primary than any we have yet found, in that it burns by a single step from carbon to carbon monoxide, and from that to dioxide. It will always give exactly the same explosion, because as soon as it burns up to a pressure and temperature where the products disintegrate it quits burning.

All manographs produce a wavy line, often said to be due to the inertia of the indicator, but really due to the characteristic of the fuel. As one becomes accustomed to looking at the diagram one can tell by the number of wiggles exactly what kind of fuel has been burned.

I hope that I have given you some idea of why we get more power from a Liberty airplane engine than from the ordinary truck engine. We select a fuel which will not break down and which will not be detrimental under the pressure and temperature used. It is well to remember, also, that the cylinder walls of a Liberty engine are very much thinner than those of a truck engine, which has a better cooling effect. One thing the engine builders have never taken into consideration is the time rate of changes in temperature. You can heat a ½-in. radiator just as hot on the outside as a 1/6-in., but nothing like as quickly. With the rapidly occurring phenomena we must take heat out just as rapidly as it is generated, to prevent the temperature from going up.

I shall not attempt an explanation of Mr. Horning's spark. As he suggests, there is a most intimate relation between electricity and heat. If you take a copper plate and connect it with a steam pipe or some heating device on one side, and a cold-water pipe on the other side, so as to get a heavy transfer of heat across the plate, and then put an electro-magnet at right angles to this, you will deflect that heat transfer up and down just as you deflect an electric current; and if you put on a magnetic

Digitized by Google

field, one side will run hot and one cold. There is an absolutely direct relationship between thermal conduction and electrical conduction. Copper is a good conductor of both electricity and heat. You will almost always find the same relationship existing; if you have a good thermal condition you have a good electrical condition.

There is an enormous amount of work to be done in studying the internal conditions of a cylinder, and it is only by improving our manographs and learning the chemical composition of our fuels that we shall ultimately get results. This work will be done, however, and I venture the prediction that within 5 yr. we shall be burning kerosene just as easily as we burn gasoline. The reason we have not made greater progress is that the problem so often proves to be just the opposite of what we thought it was. We have not solved this problem because we have not been working where it is.

Engine Power-Factor

It will be some time before we get the efficiency from an ordinary engine that we get from an airplane engine. In this work it is well to be able to make quick comparisons of some of these things. We have developed a scheme to figure rapidly on a lot of engines, basing our calculations on what we call engine power-factor. I will take a Liberty engine for illustration. It has a 5-in. bore; 5 squared is 25; times 7 is 175. Now, 175 multiplied by 1700, which is the normal rated speed of the engine, gives something like 290,000, which we call 29. In other words, if that engine has a power-factor of 1 it will give 29 hp., but that same cylinder gives 33, 34, or 35 hp. It has a power-factor of about 1.2, which is, by the way, the highest that has ever been attained with a commercial engine of any kind.

Taking a 3 by 5-in. cylinder, such as is used a great deal in motor-car work, three times 3 is 9; times 5 is 45. If we take for speed 2000 revolutions, we get about 9 hp. for a power-factor of 1. We know that the ordinary 3 by 5-in. engine does not give more than about 0.8 of 9 hp.; so you get a power-factor of 0.8.

When you have the power-factor, the figuring is very simple. Leave out the cylinder area and the π factor, and get these based on the power-factor. This is nothing less than considering the volumetric efficiency per cubic inch without actually turning it into cubic inches.

Digitized by Google

You will be surprised when you get to comparing different types of engines on that basis. You will find that kerosene engines all run down to a power-factor of about 0.6, for the simple reason that if the compression is pushed abnormally high disintegration of fuel follows, high pressures come in, and the bearings will not stand up.

We know that we can take an engine out when it is cold, step on the throttle and have a knock. For some reason the carbon knock has always been considered a mystery, but there is nothing strange about it. We have done nothing but insulate the cooling system from the gases and introduce a longer time-factor. It takes longer for heat to get through; consequently, the temperature of the gases, even though the engine be cold, is higher than it would be if the engine were clean. We can make an engine knock just as easily on a cold as on a hot day, because of the time it takes to get heat past the critical temperature at which compounds are formed. When they disintegrate they knock.

The problems of engine knocks and carbureters are problems of fuel, absolutely. We use a fuel of a given gravity, but this does not mean that it will not knock. It is just like potatoes. You buy potatoes, and specify they must average 4 oz. per potato. Some weigh ½ oz., and some 2 lb., but the total weight divided by the total number in the bushel will be 4 oz. Fuel for the Liberty engine could not be anything like that. If you had a 4-oz. potato as your guaranteed potato, they would all have to be nearly 4 oz.

MR. HORNING:—In starting up a hill on a cold morning we step on the throttle and the engine knocks. That is exactly what we get when we are running the manograph. When we start the engine cold, with the heated manifold, we get the largest weight of gas in the cylinder; with the largest weight of mixture we get the greatest weight of oxygen and also the greatest compressions, which, of course, force the explosion pressures up. About 20 sec. after the start we get the really high pressures. As the engine and manifold get hotter the weight of charge entering the cylinder becomes less; hence we get less compression. Harry Ricardo, an English engineer, calls attention to the fact that the breaking down is more dependent on pressure than it is on temperature, which our experience indicates is the case.

Mr. Kettering called attention some years ago to the

Digitized by Google

fact that in the analysis of exhaust gas you get a line of wonderful chemicals. I have noticed in our laboratory three distinct smells from the exhaust. If the exhaust is rich you get the characteristic smell that is so stifling. Gas in just the correct proportion gives another odor; a lean mixture, still another. I understand from Mr. Stratford that the analysis of lubricating oil in the bottom pan gives formaldehyde and very valuable disinfectants. These chemicals in the bottom of the crankcase were caught in the act of passing from one composition to another. They pass down into the crankcase as intermediate products. There is no doubt that we shall some day have a great industry built on extracting these valuable disinfectants from lubricating oils.

E. B. BLAKELY:—We have studied with moderate success for the last 3 or 4 yr. the problem of burning kerosene through the medium of the Hvid engine. I have not succeeded in interesting very many engineers in the investigation.

There is one very interesting feature about the Hvid engine. It has its own still. The steel cup is in effect a still, with ideal conditions for breaking down fuels, high temperature and high pressure. By altering the shape and volume of the cup, the size of the holes, and the amount of surface presented to the heat, we can distill off any fuel to the degree we want. By proper proportioning of the cup we can stop the distillation process before getting down to the heavy tars which cause most of the trouble. If engineers will give the principle a little thought, and investigate the method, they will learn something also of processes of handling heavy fuels. From this little still very close intimate information can be gained as to what is actually taking place.

Digitized by Google

A MODIFIED DESIGN OF CLASS B TRUCK ENGINE

By A F Milbrath[1]

THE design of a modification of the Class B Government standardized truck engine is presented, the principal object being a saving in weight without sacrificing either durability or safety factors. The crankcase design is rigid, but the metal is distributed so that the weight will be a minimum. The crankshafts are made of chrome-nickel steel of an elastic limit of 120,000 lb. per sq. in., which further carries out the idea of durability with low weight. The connecting-rod length is slightly more than twice that of the stroke, and this, with light-weight pistons, obviates vibration, without adding weight to the engine on account of increased cylinder height.

The flywheel and bell-housing diameters were selected with a view to securing enough flywheel weight for smooth running without increasing the engine weight materially. All-steel supports reduce breakage of arms to a minimum. The manifolds are carefully designed to give economical performance, even with low-grade fuels. A full-force-feed oiling system is employed. Provision is made for mounting starters and generators by standard S. A. E. flanges. All accessories are mounted so as to prevent interference between various units and to facilitate adjustments or removal of parts.

The return to regular commercial activities after a suspension of nearly 2 years might naturally be expected to bring with it the embodiment of ideals developed during such a period. Development is most rapid during a time of need; the newer the science or industry, the greater the progress. Truck and tractor engine designing was no exception in this case. The advancement is naturally not as great as in the newer airplane industry, but the war period has, nevertheless, left a lasting stamp on the commercial car engine.

While reports to the contrary have appeared, statistics will show that the standard military truck engines, de-

[1]Secretary and engineer, Wisconsin Motor Mfg. Co., Milwaukee, Wis.

Digitized by Google

signed under Government stimulus in Washington some 18 months ago, were a great success, and we now find that these engines will be used in a number of commercial vehicles also.

Constructional Details

To meet the demand for such service, a 4¾ by 6-in. four-cylinder engine was designed by the company with which I am associated, combining features for durability, with a total weight, however, of about 800 lb. This has been accomplished by a judicious selection and proportioning of materials, and the adoption and adaptation of many features of design of the Government standard Class B truck.

The engines are of the L-head type, having cylinders cast in pairs, with detachable heads. The heads are secured by large properly distributed studs, so that with a copper-covered gasket, water leakage at the joint is prevented. The valves have a clear diameter of 2⅛ in. and are located on the right side of the engine. Long cast-iron valve-guides are pressed into the cylinders. A chamber formed in the side of the cylinders and enclosed by an oil-tight cover-plate, protects the valve-stems and valve tappets from dust.

The water-jackets extend slightly below the travel of the piston-head and the water space increases from about ½ in. at the lower end to above 1 in. at the top. The water enters at the lowest point in the jackets, on the side opposite the valves, so that the cylinders are self-draining through the pump. The water outlet is at the highest point on the cylinder-heads.

The crankcase is cast of aluminum in two pieces, with the parting between the upper and lower halves on the center line of the crankshaft. This construction makes all of the bearings very accessible for adjustments or repairs. A bell housing is cast integrally with the crankcase and entirely encloses the flywheel. All bearings are well supported by ribs. Four through-bolts are used on each main bearing, to carry the caps, which are fitted with laminated brass shims. Through-bolts are also used for the oil-pan and front cover, where heavy gaskets are provided to make oil-tight joints. The cylinders are held down by shouldered studs with castle nuts on the inner ends.

All gears are encased in an oil-tight compartment at the front end, and by removing the front cover the cam-

Digitized by Google

shaft, idler shaft and pump-drive shaft, with their gears, can be withdrawn.

The lower half of the crankcase contains the oil sump, which extends forward only to about the center of the engine, thus giving maximum clearance for the front axle.

A large combined breather and oil filler is fitted to the forward left side of the engine and an oil level indicator is fitted on the same side near the rear end. The crankcase is so designed that the pistons may be withdrawn from the lower side.

Use of All-Steel Support

A special feature in the design of these engines is the all-steel support. Aluminum has been dispensed with for this purpose because of the softness and low strength of this material. A cast-steel or malleable iron supporting arm is bolted to the rear face of the bell-housing and a large-diameter trunnion bearing on the iron gear-cover carries the forward end. This gives a three-point suspension which relieves the engine from all twisting strains. In case a unit powerplant type of transmission is used, this bolts directly to the steel rear supporting arm.

The crankshaft is of heavy construction and made of chrome nickel steel. It is 2¼ in. in diameter on the front main bearing as well as on the crankpins. The center bearing is 2 5/16 in. in diameter and the rear 2⅜ in. The front and connecting-rod bearings are 3 in. long, the center bearing 2¾ in. and the rear 4 in. The rear bearing is also provided with collars to take up all end-thrust. A flange is forged integrally for the mounting of the flywheel. The crankshafts are sand-blasted after heat treatment to remove all scale, and the finished shafts are put into running balance. Oil-holes are drilled from the main bearings to the crankpins.

Connecting-rods are 12½ in. long, of I-beam section, drop-forged of 0.35 per cent carbon steel, and are heat treated to give maximum strength. The big ends have four chrome vanadium steel bolts and are fitted with babbitt-lined bronze bushings and laminated brass shims. The upper ends are fitted with removable bronze bushings. Oil tubes are riveted to the rods to carry lubricant from the big to the upper ends.

The pistons are made of cast iron, thoroughly sand blasted, machined and ground accurately to size. The heads are supported by cross ribs, two of which extend

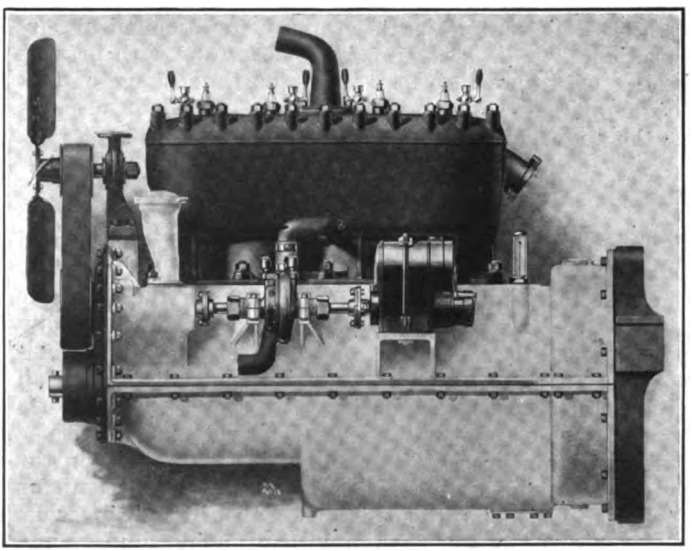
Digitized by Google

down to the piston-pin bosses. Three rings are carried at the upper, and four oil grooves at the lower end, and the pistons are relieved a short distance around the piston-pin bosses.

The piston-pins are 1⅜ in. in diameter, are turned from hollow bar steel, case-hardened and ground. They are held in the pistons by lock screws which in turn are secured by special lock washers. As a precautionary measure against scoring of cylinders, split washers are sprung into the outer ends of the piston-pin bosses to prevent the protruding of the piston-pins.

The camshaft is forged in one piece of 0.20 per cent carbon steel. The bearings are of large diameter so that the cams will clear when shafts are withdrawn. A flange is forged at the forward end to which the camshaft gear is attached by four through-bolts. The camshafts are held against a flange on the front bearing by a spring and plunger in the front gear cover. The rear end of the camshaft carries a hardened steel helical gear for driving the vertical oil-pump shaft.

The valve tappets are 1⅛ in. in diameter, are case-hardened and carry hardened steel rollers running on



SIDE VIEW OF A RECENTLY DEVELOPED SMALL MODIFIED ARMY TRUCK ENGINE FOR COMMERCIAL USE

Digitized by Google

hardened pins. Adjusting screws are fitted at the upper ends. The valve tappet guides are made of cast iron and are held in position in the crankcase by crab forgings and studs. By removing the crabs the entire tappet assembly may be removed.

The gears are 1¼ in. wide, with helical teeth, cut at an angle of 27¼ deg. The camshaft and idler gears are of cast iron, while the crankshaft and pump-drive-shaft gears are forged of steel. The idler gear is dished and is mounted on a shaft 1½ in. in diameter and 4 in. long, running in a babbitt-lined bronze bearing in the crankcase. Like the camshaft, the end-thrust is taken between a flange on the bearing and a spring plunger in the front gear cover.

All bearings, including the main and connecting-rod, the camshaft, idler and pump-drive-shaft bearings, are of babbitt-lined bronze. The bearings are bored and reamed in position in a fixture and the shafts then lapped in, with a power lapping machine, giving a full bearing before the engines are assembled. All bearings are properly grooved for lubrication, and the dimensions are such that bearing pressures are well within the limits of safety.

The exhaust and inlet manifolds are of iron, cast integrally, so that sufficient heat will be supplied to the incoming fuel to vaporize it properly for economical carburetion. This is becoming more necessary with present heavy fuels, to reduce to a minimum the leakage of fuel by the pistons, with the resulting rapid wear of all parts of the engine due to diluted lubricating oil.

Cooling and Lubricating Systems

The water circulation is by a cast-iron centrifugal pump with a bronze rotor. This pump is carried in brackets cast integrally with the crankcase on the left side or opposite the valves. The water pipes are carefully proportioned to the amount of water flowing at the various sections, and the circulation is designed to reach all vital points, such as the entire valve seats, exhaust ports and spark-plugs as well as cylinder-heads and barrels.

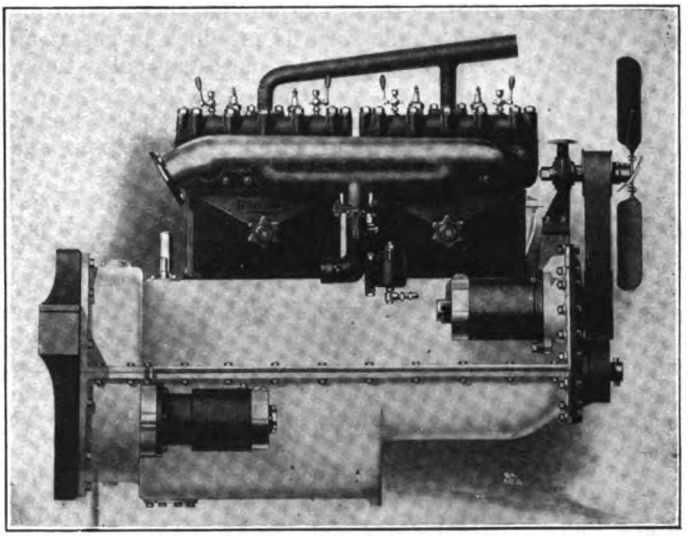
A rigid fan bracket is mounted by four studs on the front end of the crankcase, and a vertical adjustment for fan belt tension is provided. The fan belt is 2 in. wide, ample to drive an efficient fan without undue slippage and wear on the belt.

Digitized by Google

A magneto bracket is cast integrally with the crankcase and is suitable for any type of magneto, either plain or with impulse starter coupling. The magneto is driven off the rear end of the water-pump shaft through a flexible coupling.

Driven off the rear end of the camshaft, a vertical shaft is provided, which may be used as a timer or governor drive. The various commercial governors on the market can be mounted on these engines.

The lubricating system is of the force-feed type. A gear pump bolted to the crankcase and extending down



ONE OF THE LARGER SIZES OF THE SAME LINE OF ENGINE SHOWING THE GROUP ARRANGEMENT OF CYLINDERS

into the oil sump pumps the oil under pressure to a header cast into the crankcase. From the header, leads carry the oil to the main bearings, then through the drilled crankshaft to the crankpins, and through the tubes on the rods to the piston-pins. The overflow from the crankshaft and rod bearings forms a spray which lubricates the cylinders, cams and tappets. Oil pockets are provided on the camshaft bearings and idler and pump-drive-shaft bearings. An oil feed to the gears is also provided at the front end of the oil header. The small helical gears on the rear end of the camshaft run in an

Digitized by Google

oil pocket. Openings are cast leading into the valve spring chamber, so that the oil vapor can reach the valve stems.

A relief valve is fitted to the oil-pump, set to a pressure of 15 lb. per sq. in. The oil-pump is surrounded by a large strainer, removable for cleaning purposes from the bottom of the engine, without disturbing other parts.

Provision is made for mounting electric starters and generators by the S. A. E. standard flange method. The generator is carried at the forward right side of the engine and the starters on the oil-pan just ahead of the bell-housing, also on the right side. The distribution of the various accessories on these engines has been carefully worked out, so that ample room is provided to get at all units, and the valve-spring cover-plates are also unobstructed.

On the test block this engine will develop 26 hp. at 600 r.p.m., 35 hp. at 800 r.p.m., 44 hp. at 1000 r.p.m., and 52 hp. at 1200 r.p.m.

This model can also be furnished with 5-in. bore cylinders, in which case the power developed is about 10 per cent higher.

Two other sizes, a 4 by 6-in. and a 4¼ by 6-in., are also being built. These engines follow the foregoing specifications throughout with the exception that the cylinders are cast in block instead of in pairs, and the valve tappets are of the mushroom type. The various dimensions are, of course, reduced proportionately and the weight is about 660 lb.

For the smaller powers 3¾ by 5-in. and 4 by 5-in. sizes are being offered. With a few exceptions these engines follow the same general design. The weight of these models is about 525 lb.

The power developed by these latter units at 1000 r.p.m. is 33, 38, 23 and 27 hp. respectively.

Digitized by Google

BUFFALO SECTION PAPER

PROGRESSIVE AND RETROGRESSIVE DESIGNING

By Otto M Burkhardt[1]

SOME practical examples of correct as well as of incorrect methods of designing are studied, using a motor vehicle for illustration. The mechanism of such a vehicle should be very simple, and the elimination of certain links and members here and there may become more or less desirable. It is essential to know how much this will burden other members, and what strengthening or even redesigning may become necessary.

It has been proposed to eliminate the torque and radius-rods. By formulas and drawings the author shows how complex the problem is and the various changes that must follow such an attempt. A vehicle must have much stiffer springs if the torque rod is to be eliminated. This inevitably leads to a study of springs and of the influences of brakes. A vehicle can be operated at somewhat higher speed with a torque-rod. Several printed statements and diagrams are cited to show that certain fundamental principles, apparently fairly well understood, are being overlooked by designing engineers.

There is also much misconception among designers regarding crankshaft bearing sizes and loads. Taking four cases for illustration, the various problems connected with bearing loads are worked out and diagrams prepared to show results. Several tables are given summarizing data in the text and in a comparison of results, "rule of thumb" information and other highly-esteemed authority are proved to be in error.

If a designer is endowed with a limited amount of originality he may consider himself well adapted to his chosen occupation. Originality somewhat resembles fire and water; it can be dangerous if carelessly employed. Equally dangerous is the mania for imitating. In this age of commercialism we know that many imi-

[1]Mathematical research engineer, Pierce-Arrow Motor Car Co., Buffalo, N. Y.

Digitized by Google

tations of perfectly good originals have proved to be dismal failures.

I propose to discuss some practical examples representative of correct as well as wrong methods in designing. As there is perhaps nothing at present of greater interest to all of us than our means of transportation, let us study a motor vehicle.

The mechanism of a motor vehicle should, for many very obvious reasons, be a model of simplicity. In consequence the elimination of certain links and members here and there has become more or less desirable. However, if one member is to be discarded, it is essential to know how much more other members will be burdened. Frequently strengthening or even redesigning becomes necessary.

Torque and Radius Rods

Let us take as a specific example the elimination of the torque and radius rods. The reaction of the torque transmitted to the driving wheels of a motor vehicle has a tendency to lift the front wheels off the ground. In fact, if the torque were sufficient and the resistance to rolling large enough, as would be the case with fixed wheels, the chassis would turn about the driving wheels. The torque necessary to raise front wheels off the ground, as illustrated in Fig. 1, is

$$T \times R = W_f \times b$$

In this equation

T = Tractive force at circumference of driving wheels in pounds
R = Radius of driving wheels in inches
W_f = Load on front wheels in pounds
b = Length of wheelbase in inches

From this equation we find that the force tending to lift the front wheels off the ground, if a certain torque $T \times R$ is transmitted through the rear wheels, can be expressed by the equation $W_f = \frac{T \times R}{b}$

Let us denote by W the weight of a motor truck when loaded. The weights on the rear and front wheels will be about

$$W_r = \frac{3\ W}{4} \text{ and } W_f = \frac{W}{4} \text{ respectively}$$

The tractive force of heavy commercial vehicles is generally smaller than $0.6W_r$, but for passenger cars it is

Digitized by Google

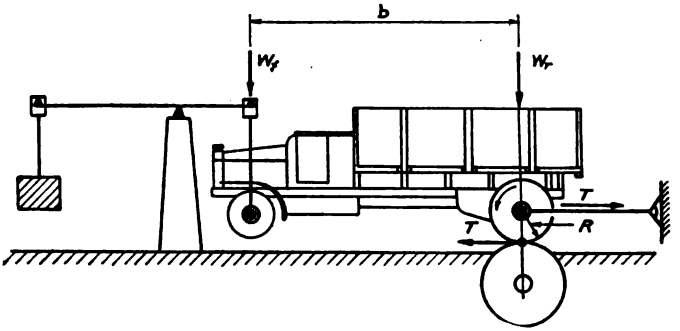


FIG. 1

frequently larger. We may, therefore, take it as a practical average value. For a wheelbase of 8.4 times the radius of the driving wheels, we find that under the given circumstances the force tending to lift the front wheels off the ground is

$$W_f = \frac{T \times R}{b} = \frac{0.6 \times W_r}{8.4} = 0.0536\ W$$

The latter amount is equal to 21½ per cent of the weight on the front wheels. As this phenomenon lends itself admirably to the determination of the tractive force, it was utilized in some well-known experiments by Professor Riedler.

We may now with advantage apply our equations to a practical example. This shall be a 5-ton truck of 20,000 lb. gross weight exclusive of unsprung weight. Hence

$$W = 20{,}000 \text{ lb.}$$

$$W_r = \frac{3\ W}{4} = 15{,}000 \text{ lb.}$$

$$W_f = \frac{W}{4} = 5000 \text{ lb.}$$

The truck is equipped with an engine developing 50 hp. at 1000 r.p.m. The total gear reduction is 50 to 1 in low gear and the efficiency of the mechanism we shall take as 80 per cent. The efficiency is usually taken as 70 per cent if the maximum drawbar pull is to be determined. The latter figure includes the rolling losses, whereas in our case only the losses between engine and rear axle can be subtracted.

Digitized by Google

We obtain therefore a driving-power reaction moment of

$$T \times R = \frac{50 \times 63{,}024}{1000} \times 50 \times 0.8 = 126{,}000 \text{ in-lb.}$$

With a 14-ft. or 168-in. wheelbase, Fig. 2, we obtain a force tending to raise the front axle of

$$W'_f = \frac{126{,}000}{168} = 750 \text{ lb.}$$

The chassis shown in Fig. 2 is provided with a torque rod. This member, as is well known, is employed to impart the wheel-power reaction to the frame. As the torque rod is 50 in. long, it is evident that the pressure exerted at the front end of it is

$$P' = \frac{126{,}000}{50} = 2520 \text{ lb.}$$

This pressure is comparatively small and easily taken care of.

As a single force cannot balance a couple, we must have another force equal and opposite to P' with its point of application in the center of the axle. The latter force, being the reaction of the former, has been denoted by P''. We shall now resolve the force P' into two components P'_f and P'_r with their points of application in the centers of the front and rear axles respectively. The former of the two components is what we have thus far known as W'_f, as we shall presently see. It is

$$P'_f = \frac{P' \times 50}{168} = \frac{2520 \times 50}{168} = 750 \text{ lb.} = W'_f$$

$$P'_r = \frac{P' \times 118}{168} = \frac{2520 \times 118}{168} = 1770 \text{ lb.}$$

If we now subtract P'_r from P'' we obtain

$$P'' - P'_r = 2520 - 1770 = 750 \text{ lb.}$$

The force $P'' - P'_r$ is therefore also equal to W'_f, but acting in the opposite direction.

From this it follows that when maximum torque is transmitted through the rear wheels, the respective loads on the rear and front wheels have changed to

$$W''_r = W_r + W'_f = 15{,}750 \text{ lb. and}$$
$$W''_f = W_f - W'_f = 4250 \text{ lb.}$$

Let us now take another torque rod the same length as the one just considered but anchored to the rear axle in such a way that both ends can be fastened to the frame

Digitized by Google

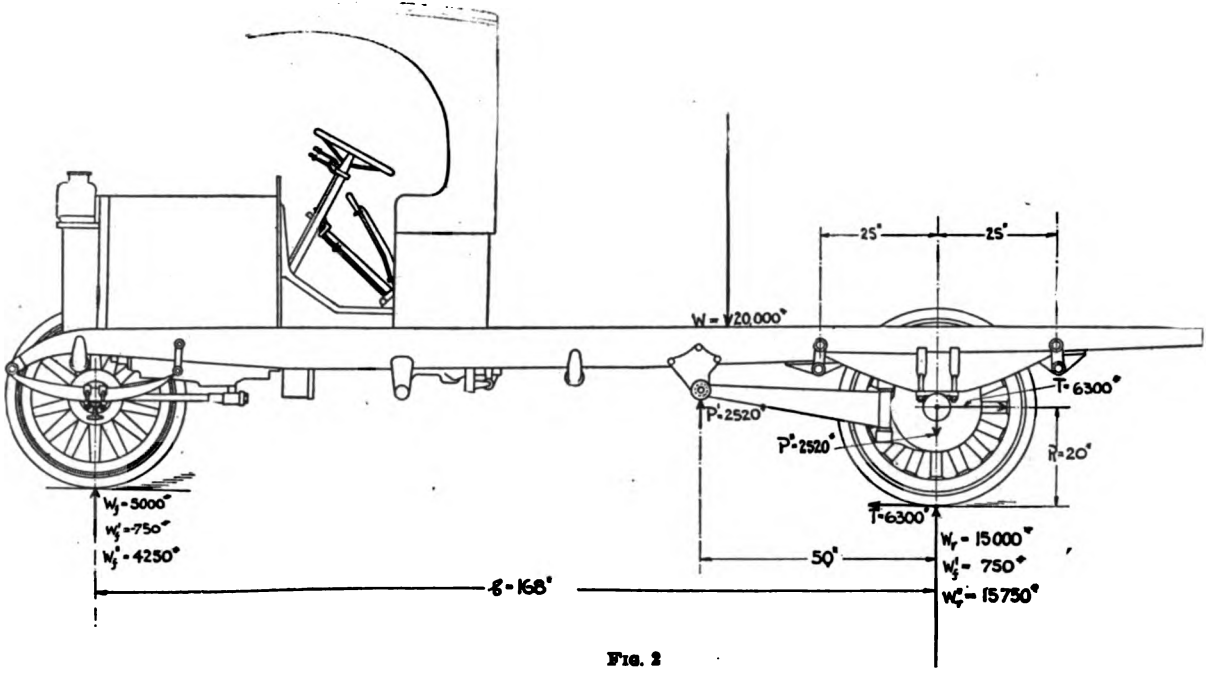


FIG. 2

Digitized by Google

at equal distances from the center of the rear axle. It is evident that in this case the pressures on both ends of the torque rod will be the same, i.e., 2520 lb. If, however, we choose a rear spring to take the place of the torque rod the whole condition is changed.

To prove our contention a chassis has been shown in Fig. 3, in which the springs take the place of the torque rod. With the same power and gear ratio we have the same driving power reaction moment as before, *i.e.* 126,000 in-lb. The force couple constituting this driving power reaction moment we have denoted by P' and P''. It is in this case

$$P' = P'' = \frac{126{,}000}{25} = 5040 \text{ lb.}$$

Resolving P' into P'_f and P'_r gives

$$P'_f = \frac{5040 \times 25}{168} = 750 \text{ lb.}$$

$$P'_r = \frac{5040 \times 143}{168} = 4290 \text{ lb.}$$

Since $P'_f = W'_f$ we have as in the former case

$$W''_f = W_f - P'_f = 5000 - 750 = 4250 \text{ lb. and}$$
$$W''_r = W_r + P'' - P'_r = 15{,}750 \text{ lb.}$$

The force P'' must be considered as an addition to the weight of the rear axle. Now it must be conceded that it is essential to reduce all unsprung weight to a minimum. The spring-supported weight acting on the front wheels of either chassis is as previously pointed out

$$W_f - P'_f = 5000 - 750 = 4250 \text{ lb.}$$

Hence the load per spring bolt is

$$\frac{4250}{4} = 1062.5 \text{ lb.}$$

Similarly the spring-supported weight acting on the rear wheels of the chassis with the torque rod shown in Fig. 2 is

$$W_r - P'_r = 15{,}000 - 1770 = 13{,}230 \text{ lb.}$$

and the load per spring bolt is

$$\frac{13{,}230}{4} = 3307.5 \text{ lb.}$$

The spring-supported weight acting on the rear wheels of the chassis without torque rod, Fig. 3, is

Digitized by Google

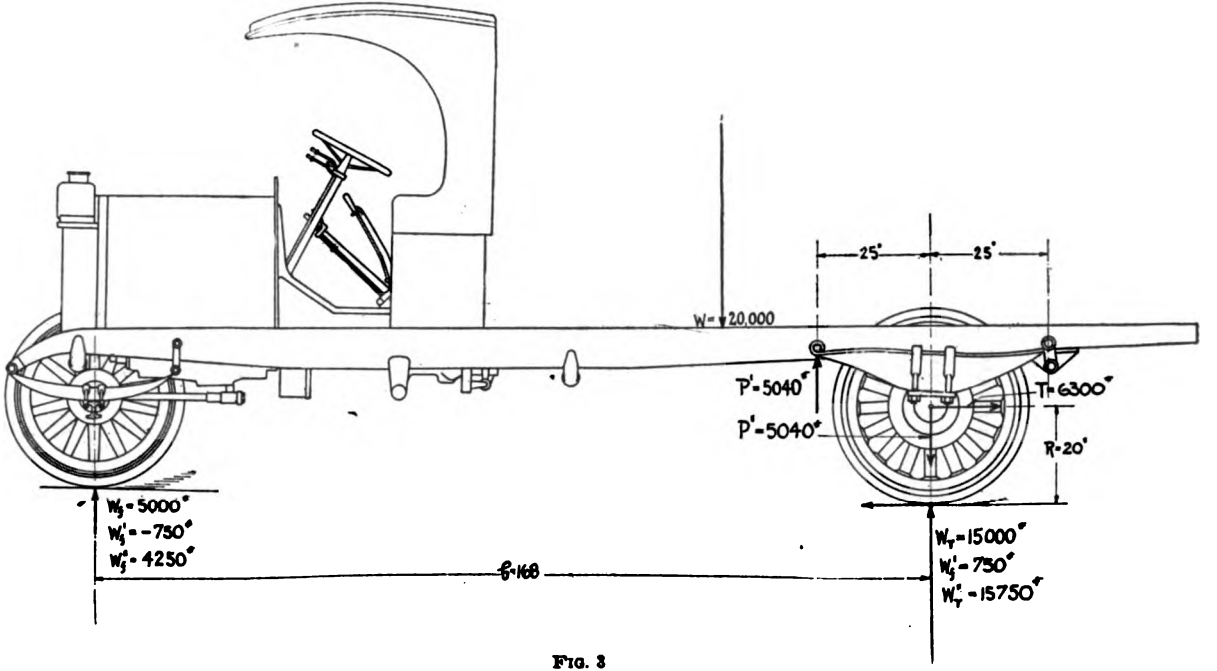


FIG. 3

Digitized by Google

$$W_r - P'_r = 15{,}000 - 4290 = 10{,}710 \text{ lb.}$$

The load on two of the rear spring bolts is consequently

$$\frac{10{,}710}{2 \times 2} = 2677.5 \text{ lb.}$$

while the other two each carry a load of

$$2677.5 + 2520 = 5197.5 \text{ lb.}$$

Influence of Brakes

Before we can draw any definite conclusions with regard to the maximum load on the springs we have to consider what happens when the brakes are applied. If the brakes are in good condition and applied with some force, it should be possible to lock the wheels. This elicits a braking power moment of about

$$15{,}000 \times 0.6 \times 20 = 180{,}000 \text{ in-lb.}$$

This braking power acts in a direction opposite to the driving power and consequently the directions of the forces constituting the reaction are reversed, or, in case of the Hotchkiss drive, Fig. 3, the rear halves instead of the front halves of the rear springs impart the reaction to the chassis. We observe that the braking power is 43 per cent larger than the driving power. In determining this figure no account has been taken of the amount of load of which the rear wheels are relieved if the brakes are applied, because the braking power may be even larger, as stated, if chains are used.

Now in the chassis shown in Fig. 2 we have when the brakes are applied an addition to the spring-supported load of

$$P' = P'' = \frac{180{,}000}{50} = 3600 \text{ lb.}$$

This is distributed over the front and rear axles in inverse proportion to the distances; hence

$$P'_f = P' \times \frac{50}{168} = 1070 \text{ lb. and}$$

$$P'_r = P' \times \frac{118}{168} = 2530 \text{ lb.}$$

The loads on the front and rear wheels are

$$W''_f = W_f + P'_f = 5000 + 1070 = 6070 \text{ lb. and}$$

$$W''_r = W_r - P'' + P'_r = 15{,}000 - 3600 + 2530 = 13{,}930 \text{ lb.}$$

The maximum spring-supported weight acting on the

Digitized by Google

front wheels is 6070 lb. Hence the load per front spring bolt is

$$\frac{6070}{4} = 1517.5 \text{ lb.}$$

The maximum spring-supported weight acting on the rear wheels is

$$W_r + P'_r = 15{,}000 + 2530 = 17{,}530 \text{ lb.}$$

The maximum load per rear-spring bolt therefore is

$$\frac{17{,}530}{4} = 4382.5 \text{ lb.}$$

as against a nominal load, for which the springs are generally designed, of

$$\frac{15{,}000}{4} = 3750 \text{ lb.}$$

From this it follows that, if a torque member is provided, the springs are subjected to an overload of less than 17 per cent under the worst condition.

In the chassis without the torque rod, Fig. 3, we have when the brakes are applied

$$P' = P'' = \frac{180{,}000}{25} = 7200 \text{ lb.}$$

The load P' is acting on the two rear bolts of the rear springs. It is balanced by the two loads P'_f and P'_r. It is

$$P'_r = P' \times \frac{168 + 25}{168} = 8270 \text{ lb.}$$

In this case it must be noted that P'_f is negative, acting in the opposite direction to P'. This is evident from the point of application of P'. Since $P' = P'_r + P'_f$ it follows:

$$P'_f = 7200 - 8270 = -1070 \text{ lb.}$$

The loads on front and rear wheels are now

$$W''_f = W_f - P'_f = 5000 + 1070 = 6070 \text{ lb.}$$

$$W''_r = W_r - P'_r + P'' = 15{,}000 - 8270 + 7200 = 13{,}930 \text{ lb.}$$

From this it follows that the maximum spring-supported weight on the front wheels is 6070 lb.; hence the load per spring bolt is

$$\frac{6070}{4} = 1517.5 \text{ lb.}$$

Digitized by Google

Furthermore, the front bolts of the rear springs carry a load of

$$\frac{15{,}000 - 8270}{4} = 1682.5 \text{ lb.}$$

The rear bolts of the rear springs are loaded with

$$1682.5 + \frac{7200}{2} = 5282.5 \text{ lb.}$$

The different results so far obtained are given in the table on page 633.

From the table we observe that the rear springs for all forward speeds have to carry less load than when the vehicle is standing still. The difference is 12 per cent for low-gear driving. In the vehicle without a torque member the rear springs under all running conditions have to carry more than the nominal load when vehicle is standing still. The increase in load is about 40 per cent for low-gear driving as well as when the brakes are applied. From this it follows that much stiffer springs must be fitted to a vehicle if the torque rod is to be eliminated. Of two vehicles designed according to a certain standard of engineering, the one with the torque rod necessarily must be by far the better for riding.

Fig. 3 illustrates how unequally the springs deflect. This accounts for the well-known phenomenon that in most of the Hotchkiss-drive arrangements as we know them today the brakes hold all right if applied gently, but not if applied vigorously. The trouble with loose spring clips, closely associated with the Hotchkiss-drive arrangement, is also so well known that it needs no further mention. Furthermore, it is well known that the speed of the vehicle is dependent upon the suspension. A vehicle equipped with a torque rod may, therefore, safely be operated at somewhat higher speed than one without this member.

Thus far we have assumed that the reaction of the tractive force is a constant drawbar pull acting in the center of the rear axle. In practice the tractive force is generally utilized to accelerate the gross weight of the vehicle, and to overcome road resistance or resistance due to gradients. During acceleration the reaction of the tractive force has its point of application in the center of gravity of the vehicle. When gradients are negotiated at a constant rate of speed or under other constant running conditions, the reaction has its point of applica-

Digitized by Google

	Load on front wheels, lb.	Load on rear wheels, lb.	Load per front spring bolt, lb.		Load per rear spring bolt, lb.			
					In front of axle		Back of axle	
			Nominal	Actual	Nominal	Actual	Nominal	Actual
Driving in Low Gear								
Chassis with torque rod.....	4,250	15,750	1,250	1,062.5	3,750	3,307.5	3,750	3,307.5
Chassis without torque rod..	4,250	15,750	1,250	1,062.5	3,750	2,677.5	3,750	5,197.5
Brakes Applied								
Chassis with torque rod.....	6,070	13,930	1,250	1,517.5	3,750	4,382.5	3,750	4,382.5
Chassis without torque rod..	6,070	13,930	1,250	1,517.5	3,750	1,682.5	3,750	5,282.5

Digitized by Google

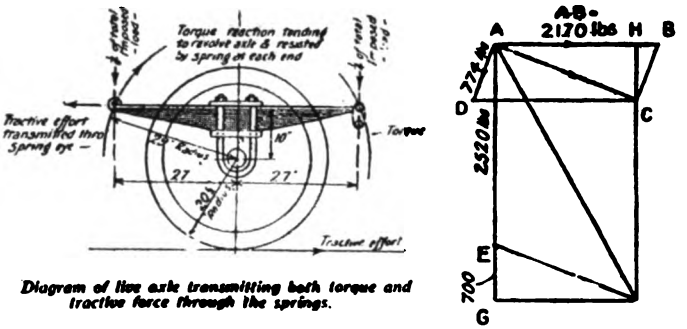


Diagram of live axle transmitting both torque and tractive force through the springs.

FIG. 4

tion in the front end of the radius rods, if such are provided, or in the front spring-bolts in the Hotchkiss-drive arrangement.

Now every engineer knows that the center of gravity of a motor vehicle, as well as the other points of reaction already mentioned, are generally farther from the ground than the center of the rear axle. Consequently we have in these cases to deal with a driving-force reaction moment of much greater magnitude than those thus far considered.

Such fundamental principles are being neglected. This we see from Figs. 4 and 5, which are reproduced from articles in one of the leading trade papers. In Fig. 4 we note that the writer states, "Torque reaction resisted by spring at each end." This we have proved to be an erroneous conception. Furthermore, we learn from the magnitude of the forces that the writer imagines the reaction of the tractive force to be acting in the center of the axle, whereas in reality it is acting through the top leaf of the spring. The writer shows it there but neglects it, thus making it appear to be good designing to place the spring far above the axle.

It is quite natural that almost nobody, least of all an advocate of the underslung-spring design, can reconcile himself to such a conclusion. This, however, is no reason why another hypothesis should be invented, since in an exact science like mathematics or mechanics there is no need for hypotheses. Nevertheless, we find in another article by a well-known company the opinion that a load

Digitized by Google

acting vertically in the center of a perfectly symmetrical spring can impose unequal loads on the spring-bolts. Fig. 5 is a reproduction from this article and shows the fallacy.

Crankshaft Bearing Sizes and Loads

I have found a good deal of misconception among designers in regard to crankshaft-bearing proportions. This impelled me to derive a scientific basis of design from the axiom that the capacity of a bearing is primarily a function of the load it has to carry, rubbing velocity and temperature being the same in all cases. This axiom, however, requires a separate analysis for each category of engines. I shall therefore limit the present investigation to the most popular of all engines today, the four-cylinder, four-stroke cycle internal-combustion engine. A further although less important limitation is that the engine is understood to be designed to propel a motor truck.

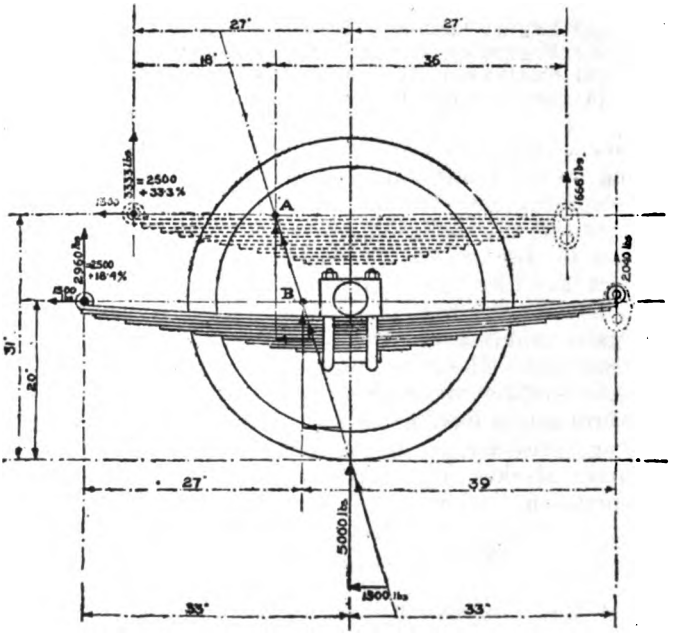


Fig. 5

Digitized by Google

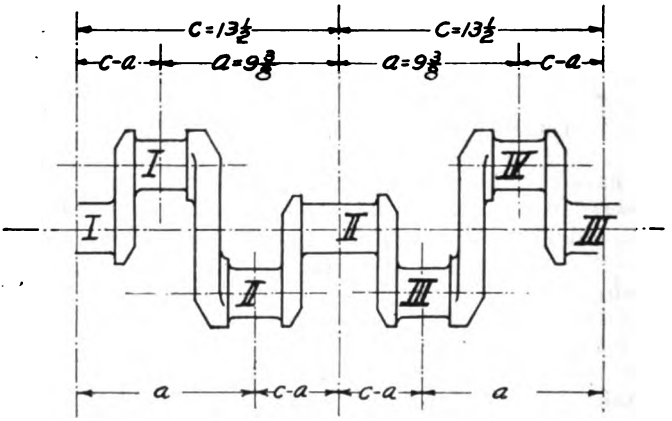


FIG. 6

First of all, it is necessary that we ascertain the bearing loads pertaining to the four limiting modes of propulsion:

(1) Engine running light at low speed
(2) Engine running at low speed under full power
(3) Engine running light at maximum speed, 1000 r.p.m.
(4) Engine running at maximum speed under full power

Case I We find, with regard to Case I, that the loads acting on the crankshaft will necessarily be very small, in fact negligible. We may therefore from the beginning dismiss this case as uninfluential.

Case II Because of the low speed, we may in this case neglect the centrifugal and inertia forces. There are then left for further consideration the pressures due to the gaseous mixture, during the expansion and compression strokes. The mean pressure acting during the expansion stroke we shall denote by P, and the mean pressure acting during the compression stroke by p. The average pressure, p', on any one crankpin for four consecutive strokes, i.e., expansion, exhaust, suction and compression, is then

$$p' = \frac{P + O + O + p}{4} = \frac{P + p}{4}$$

From the diagram in Fig. 10, which is designed for one particular engine, to be specified later, we obtain

Digitized by Google

$P = 2380$ and $p = 272.5$. Hence for this specific case we obtain an average crankpin pressure of

$$p' = \frac{2380 + 272.5}{4} = 663 \text{ lb.}$$

The crankpin load is imparted to the main bearings in definite proportions. Referring to Fig. 6, we note that these partial loads on main bearing I may be expressed as follows:

Expansion in cylinder I $= P \times \frac{a}{c}$ lb.

Exhaust in cylinder I $= 0$ lb.
Suction in cylinder I $= 0$ lb.

Compression in cylinder I $= p \times \frac{a}{c}$ lb.

Expansion in cylinder II $= P \times \frac{c-a}{c}$ lb.

Exhaust in cylinder II $= 0$ lb.
Suction in cylinder II $= 0$ lb.

Compression in cylinder II $= p \times \frac{c-a}{c}$ lb.

From this we derive that the average pressure on the main bearing I during one complete cycle is expressed by

$$p' = \frac{P\frac{a}{c} + p\frac{a}{c} + P\frac{c-a}{c} + p\frac{c-a}{c}}{4} = \frac{P+p}{4}$$

Identically the same loads as enumerated above are imparted on main bearing III in consequence of the forces acting in cylinders III and IV. All forces here under consideration are acting in the same direction. It is therefore evident that the average load on the center bearing must be the difference between the sum of all the average loads acting on the four crankpins less those resisted by the two end bearings; hence, the average pressure on the center bearing during four strokes is

$$p'' = 4 \times \frac{P+p}{4} - 2 \times \frac{P+p}{4} = \frac{P+p}{2}$$

For our particular example we obtain for the end bearings I and III an average pressure of

$$p' = \frac{2380 + 272}{4} = 663 \text{ lb.}$$

Digitized by Google

and for the center bearing we obtain

$$p'' = \frac{2380 + 272}{2} = 1326 \text{ lb.}$$

Case III We may neglect the pressures due to the gaseous mixture in this case. The only forces to be considered are those due to the inertia of the reciprocating parts and the centrifugal forces. Now as the inertia forces are affected by the angularity of the connecting-

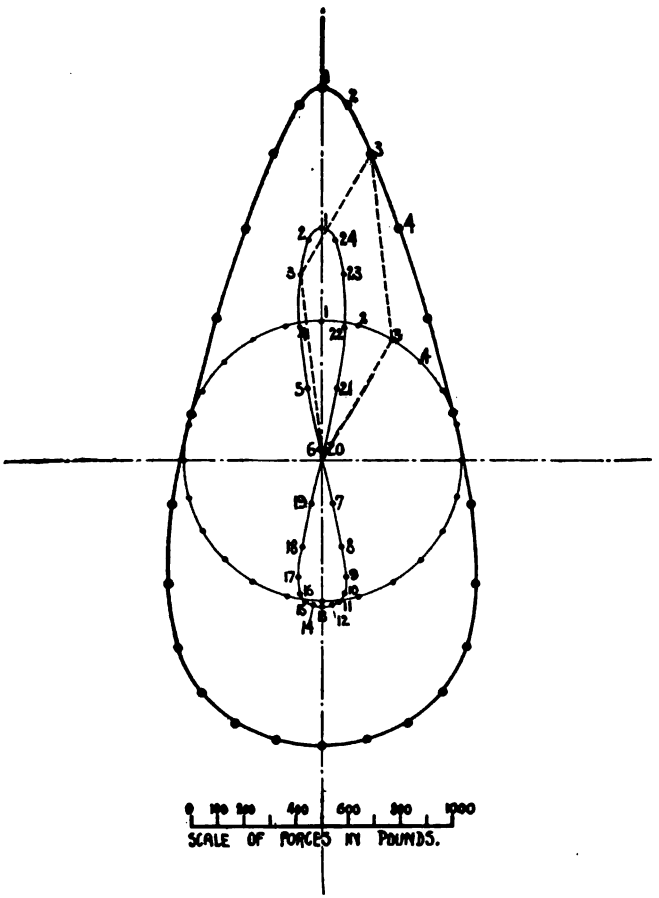


FIG. 7

Digitized by Google

rod, and as the centrifugal force is continually changing its direction, no simple universal formula can be evolved from which to determine the magnitude and direction of the various mean pressures, as in the former case. I shall therefore confine myself to one particular example.

In a four-cylinder engine of 4½-in. bore and 6¾-in. stroke the total reciprocating weight consisting of piston with pin, rings, set-screw and the small end of the connecting-rod, is 7½ lb. The total rotating weight acting on one crankpin is 5½ lb. The inertia and centrifugal forces are all calculated for 1000 r.p.m. of the engine.

The graphical representation of magnitude and direction of the inertia forces acting on the crankpin during one revolution resembles a lemniscate, as shown in Fig. 7. This diagram of forces includes certain horizontal component forces which have their origin in the angularity of the connecting-rod. The concentric circle shown in the same figure represents the centrifugal forces, 530 lb., acting on the crankpin. If now the inertia forces are combined with the centrifugal forces, as indicated by the dotted lines for one crank position, we obtain a diagram of elliptical shape which represents the magnitude and direction of the resulting loads on the crankpin.

From the last named diagram we find that the maximum load on the crankpin is 1415 lb., the minimum load 530 lb. and the average load 940 lb. These crankpin loads are imparted to the main bearings in definite proportion, as emphasized in Case II. The partial loads ascertained according to the proportions derived from Fig. 6 are graphically represented on a larger scale in Fig. 8, where they are designated as $\frac{a}{c}$ and $\frac{c-a}{c}$ portions of the total crankpin load.

To determine the load on the end bearings, we have to combine components 1, 2, 3 and so on to 24 of the $\frac{a}{c}$ diagram with simultaneously acting component forces of $\frac{c-a}{c}$ diagram, i.e. with 13, 14, 15 and so on to 12. This yields the diagram of resulting forces which is marked "Resulting loads imparted on end bearings I and III."

Identically the same principle of combination must be followed in determining the loads on the center bearing.

Digitized by Google

Since, however, the center bearing is affected by all loads on either of the four crankpins, it is evident that the resulting loads are all twice as large as those acting on the end bearings.

In the present case we have to consider further the centrifugal forces due to the crankpins and the adjacent crank-cheeks. The crankpin and those portions of the adjacent crank-cheeks which are not balanced in their own plane weigh for the engine under consideration about 6 lb. The centrifugal force due to this mass is 575 lb. at 1000 r.p.m. If we denote this centrifugal force by C we find with reference to Fig. 6 that main bearings I and III each receive the partial loads

$$L_e = C\frac{a}{c} - C\left(\frac{c-a}{c}\right) = C\left(\frac{2a-c}{c}\right)$$

Substituting the dimensions given in Fig. 6, we obtain

$$L_e = 575 \times \frac{2 \times 9\frac{3}{8} - 13\frac{1}{2}}{13\frac{1}{2}} = 225 \text{ lb.}$$

Again, the load on the center bearing is twice as large as the load on either end bearing; hence 450 lb. We can now determine the total load on the end bearing, which by virtue of the existing symmetry at the same time represents one-half of the total load acting on the center bearing.

In Fig. 9 we recognize the triangular thin-line diagram as the one representing the loads imparted by connecting-rods I and II, respective III and IV on the end bearings, while the concentric circle represents the above determined centrifugal force of 225 lb. If corresponding forces of these two diagrams are combined in proper phase as indicated by dotted lines we obtain the final resulting forces acting on the end bearings. The resulting diagram in heavy lines shows a maximum load of 875 lb., a minimum load of 385 lb., and by summation we obtain the average load of 600 lb. While these loads have direct reference to the two end bearings we can find from them the loads on the center bearing by simply multiplying the former by two. This gives a maximum load of 1750 lb., a minimum load of 730 lb., and an average load of 1200 lb.

Case IV In this case we have to deal with the forces due to the gaseous mixture as well as with centrifugal and inertia forces. While I do not underestimate the difficulty of determining exactly the forces acting during

Digitized by Google

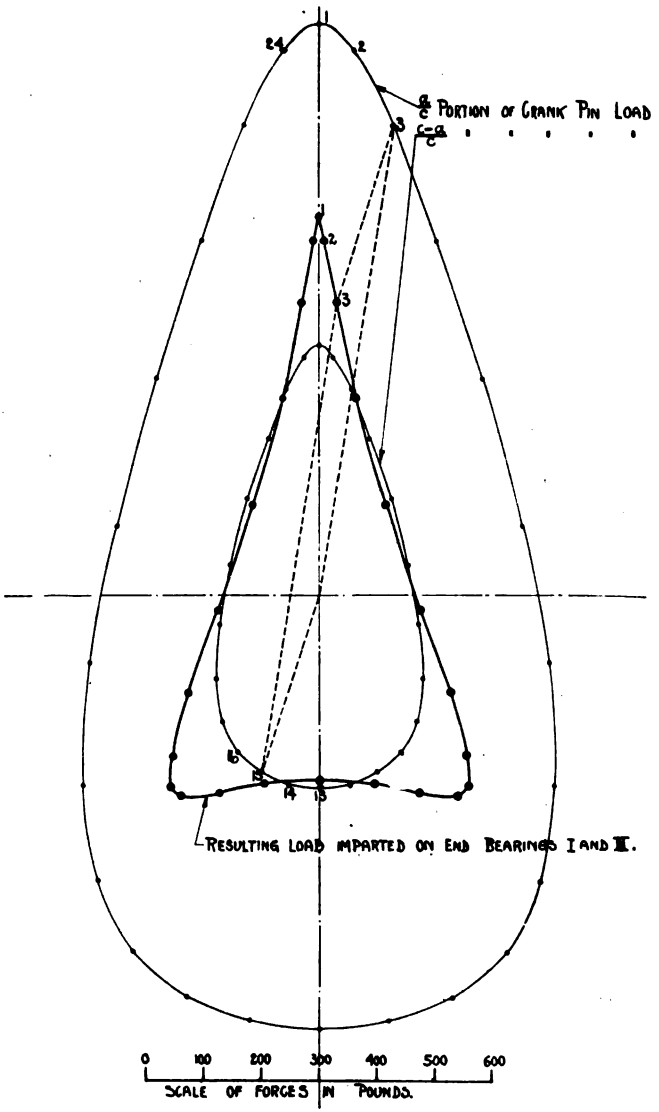


Fig. 8

Digitized by Google

the expansion and compression strokes, it is also certain that a fair estimate of these forces can be derived from the diagram shown in Fig. 10. This has been designed to conform as nearly as possible with indicator diagrams as known from actual practice. It represents a total of 1040 ft.-lb. of work, which in case of a four-cylinder engine when running at 1000 r.p.m. would mean

$$\frac{1040 \times 4 \times 500}{33{,}000} = 63 \text{ indicated hp.}$$

If we allow about 14 per cent for engine friction, we obtain an effective output of 54 hp. This in turn corresponds to a mean effective pressure of 100 lb. per sq. in. of piston area. This may be somewhat higher than that generally obtained with truck and tractor engines; it is, however, less than the rather desirable standard set by aircraft engines which we endeavor to approach. One hundred pounds may therefore be chosen, not only because it is an even figure but because it is what we hope to obtain from engines in the future.

With this mean effective pressure as a basis it may be mentioned that the horsepower output at 1000 r.p.m. can be determined for any similar engine by the simple formula

$$HP = \frac{b^2 s n}{10}, \text{ where}$$

b = bore in inches
s = stroke in inches
n = number of cylinders

The various pressures due to the gaseous mixture as taken from Fig. 11, together with the inertia forces, as well as certain horizontal components due to the angularity of the connecting-rod, are represented graphically by the irregular thin-line diagram, Fig. 10. It is of course evident that for the expansion stroke we find forces of considerable magnitude, while for the next three strokes the inertia forces are prevailing. This accounts for the reappearance of the same force diagram that we used in Fig. 7. The concentric circle shown in Fig. 10 represents the centrifugal force acting on the crankpin. If we now combine corresponding forces as before, we obtain the total load on the crankpin as represented by the heavy-line diagram.

Digitized by Google

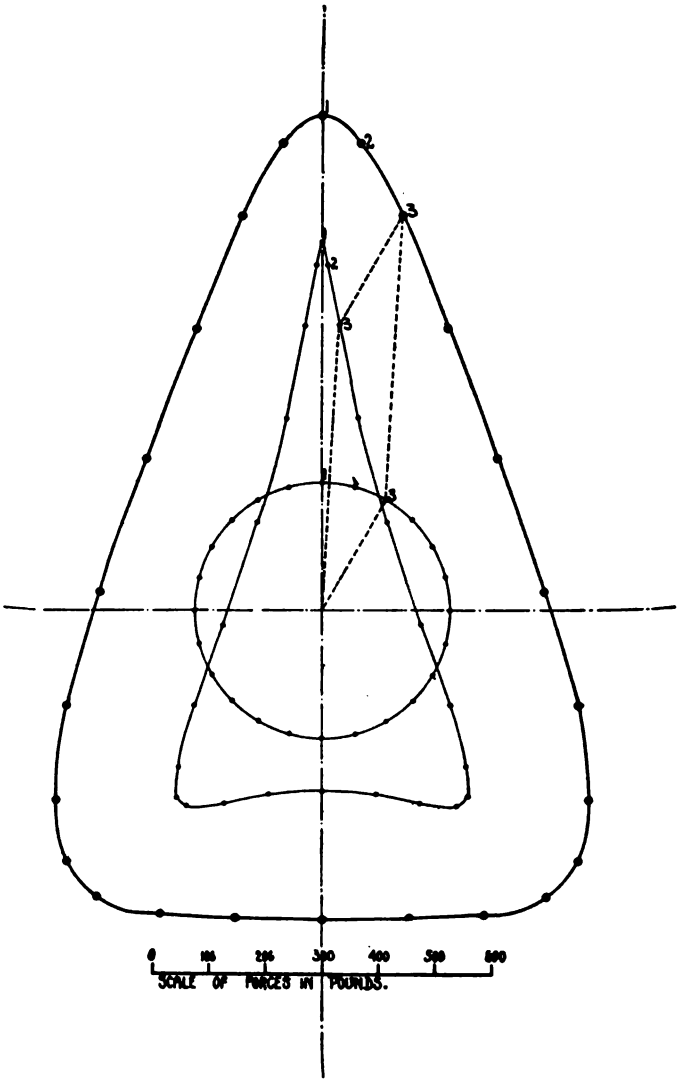


FIG. 9

Digitized by Google

From the latter we obtain the following characteristic loads:

Maximum = 4075 lb.
Minimum = 530 lb.
Average = 1230 lb.

These loads are imparted to the main bearings in proportion $\frac{a}{c}$ $\frac{c-a}{c}$. These partial loads are represented

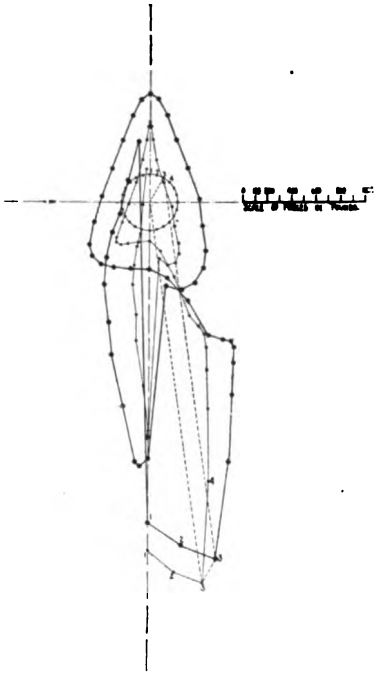


FIG. 10

in Fig. 12. Now to obtain from these the load on the end bearings we have to combine forces 1, 2, 3 and so on to 24 of the $\frac{a}{c}$ graph with forces 13, 14, 15 and so on to 1 of the $\frac{c-a}{c}$ graph. This yields the irregular thin-line diagram shown in Fig. 13. If the resultant forces so obtained are now combined with the centrifugal forces shown in the same figure, we obtain the heavy-line dia-

Digitized by Google

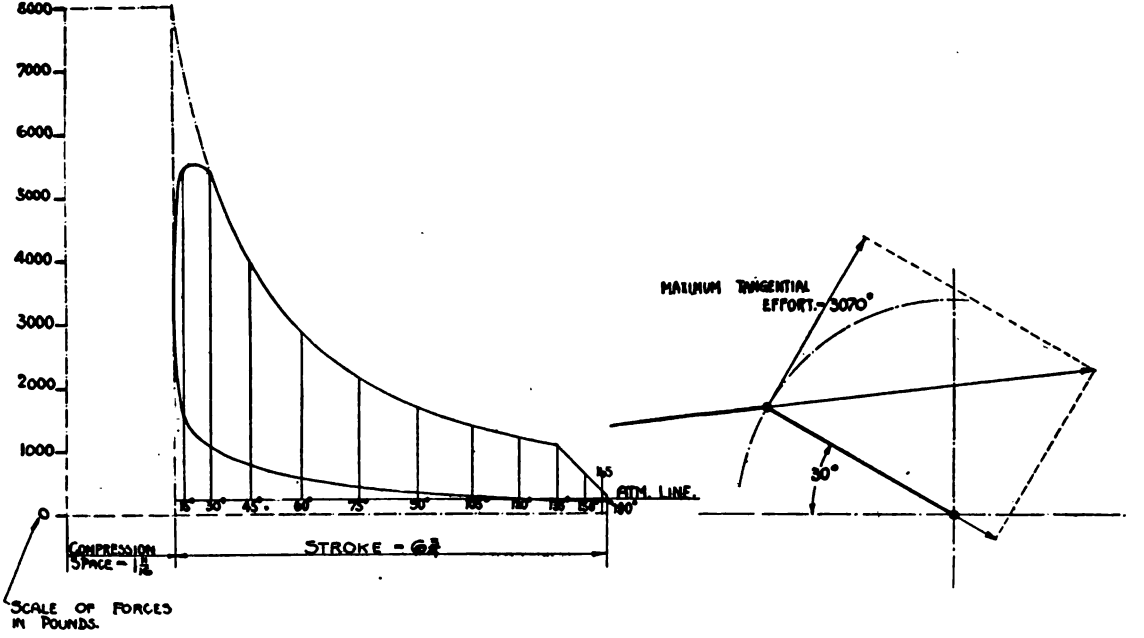


FIG. 11

Digitized by Google

gram which represents the resulting forces acting on the end bearings.

The characteristic loads obtained from this diagram are

Maximum = 2945 lb.
Minimum = 380 lb.
Average = 1000 lb.

To obtain the loads on the center bearing due to crankpins 1 and 2, we have first to combine forces 1, 2, 3 and

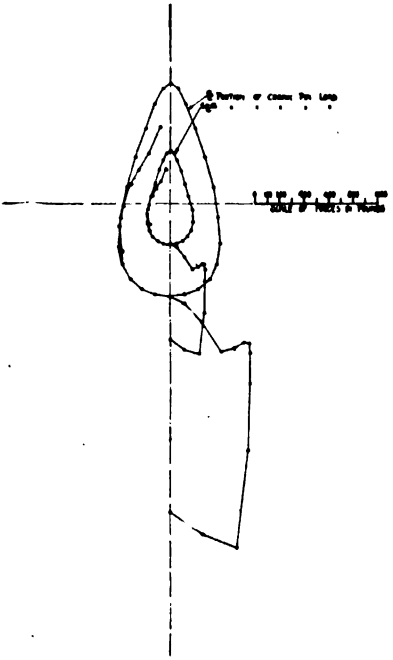


FIG. 12

so on to 48 of the $\frac{c-a}{c}$ diagram with 13, 14, 15 and so on to 1 of the $\frac{c}{a}$ diagram. This yields the diagram shown in Fig. 14. This diagram also represents the forces on the center bearing due to crankpins 3 and 4. We must however bear in mind that the latter are in phase 360 deg. behind the former. If we therefore combine forces 1 to 24 of the diagram in Fig. 14 with forces

Digitized by Google

25 to 48 of the same diagram, we obtain the irregular thin-line diagram shown in Fig. 15.

If these forces are in turn combined with the centrifugal forces also shown in Fig. 15, a final diagram is obtained which represents the total load on the center bearing.

We obtain from this diagram the following characteristic bearing loads:

Maximum = 2690 lb.
Minimum = 580 lb.
Average = 1500 lb.

It may now be mentioned that the same force diagram is obtained for either firing order 1-3-4-2 or 1-2-4-3.

TABLE I—LOADS ON VARIOUS ENGINE BEARINGS

Running condition of engine	Character of load	Load in Lb. Crank-pin	End bearings	Center bearings
Low speed ...	Maximum	5,200	3,600	3,600
Full power ...	Average	663	663	1,326
	Relative bearing length	1	1	2
High speed ..	Maximum	1,415	875	1,750
Zero power ..	Average	940	600	1,200
	Relative bearing length	1	0.64	1.28
High speed...	Maximum	4,075	2,945	2,690
Full power ...	Average	1,230	1,000	1,700
	Relative bearing length	1	0.812	1.380

The various bearing loads thus far obtained are compiled in Table I. In this table certain relative figures are also given representing the different bearing lengths. The crankpin length has been taken as unity. These relative figures presuppose that the crankpins and the main bearings are of equal diameters, which is considered good practice for three-bearing shafts.

From the first group of forces pertaining to low engine speed and full horsepower output we note that the effective lengths of the crankpin, the end bearings and the center bearing should be in proportion 1 to 1 to 2 re-

Digitized by Google

spectively. From the second group of forces we note that for high engine speed and zero power output the effective bearing lengths should be made in proportion 1 to 0.64 to 1.28. Finally, for high-speed and maximum power output requirements the bearing lengths should be made in proportion 1 to 0.812 to 1.380.

To pay adequate attention to the various factors given in Table I means to compromise. For instance, the engine under consideration will run at high speed, nearly 1000 r.p.m., about 80 per cent of its life, whereby it develops power varying from zero to maximum output. The limiting conditions are Cases III and IV. The bearing lengths required to conform with this running condi-

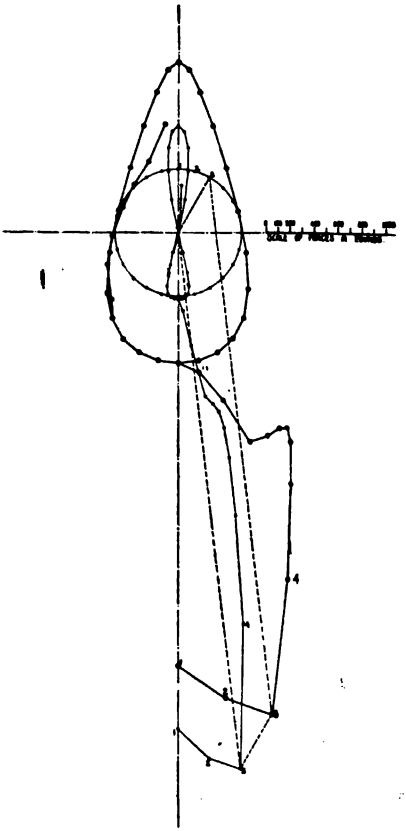


FIG. 13

Digitized by Google

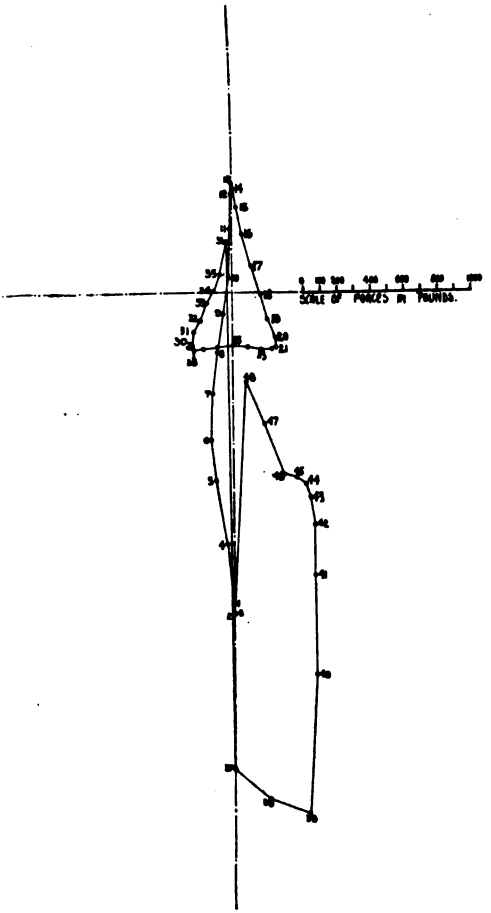


FIG. 14

tion are the mean of the lengths determined for the limiting cases; hence,

$$\text{Relative end bearing length} = \frac{0.64 + 0.812}{2} = 0.726$$

$$\text{Relative center bearing length} = \frac{1.28 + 1.38}{2} = 1.33$$

We are at present concerned with the problem of minimizing the unavoidable wear and preventing uneven

Digitized by Google

wear which cause unnecessary stresses in the structural parts. This requires that adequate attention be given also to the remaining 20 per cent of the engine's life during which it is running at low speed and developing full power for acceleration and hill-climbing, as investigated in Case II. This consideration elicits the following final proportions:

Relative crankpin length = 1
Relative end bearing length =
80% of 0.726 + 20% of 1 = 0.78
Relative center bearing length =
80% of 1.33 + 20% of 2 = 1.46

Let us choose for our example an effective crankpin length of 2½ in. We then obtain end bearing length of

$$0.78 \times 2\tfrac{1}{2} = 1\ 15/16 \text{ in.}$$

and a center bearing length of

$$1.46 \times 2\tfrac{1}{2} = 3\tfrac{5}{8} \text{ in.}$$

The front end bearing should be lengthened about 5/16 in. to allow for the load, due to the timing-gears, whereas at least 1-in. effective length should be added to the rear end bearing to compensate for the effect of the clutch and the flywheel. Allowing further ⅛ in. for each fillet, we obtain the following compilation:

TABLE II

Bearing	Nominal length, in.	Allowance for fillets, in.	Other allowances, in.	Actual length, in.
Crankpin	2½	2 × ⅛ = ¼		2¾
Front end	1 15/16	⅛	5/16	2⅜
Rear end	1 15/16	⅛	1 1/16	3⅛
Center	3⅝	2 × ⅛ = ¼		3⅞

Some consideration may now be given to the diameters of the crankpins and the journal bearings. In Fig. 11 I have shown that the maximum tangential effort is 3070 lb. This force when exerted on crankpins I or III can be resisted only through forces set up in crankpins II and IV respectively. The lever arm on which the force of 3070 lb. acts is the distance between the centers

Digitized by Google

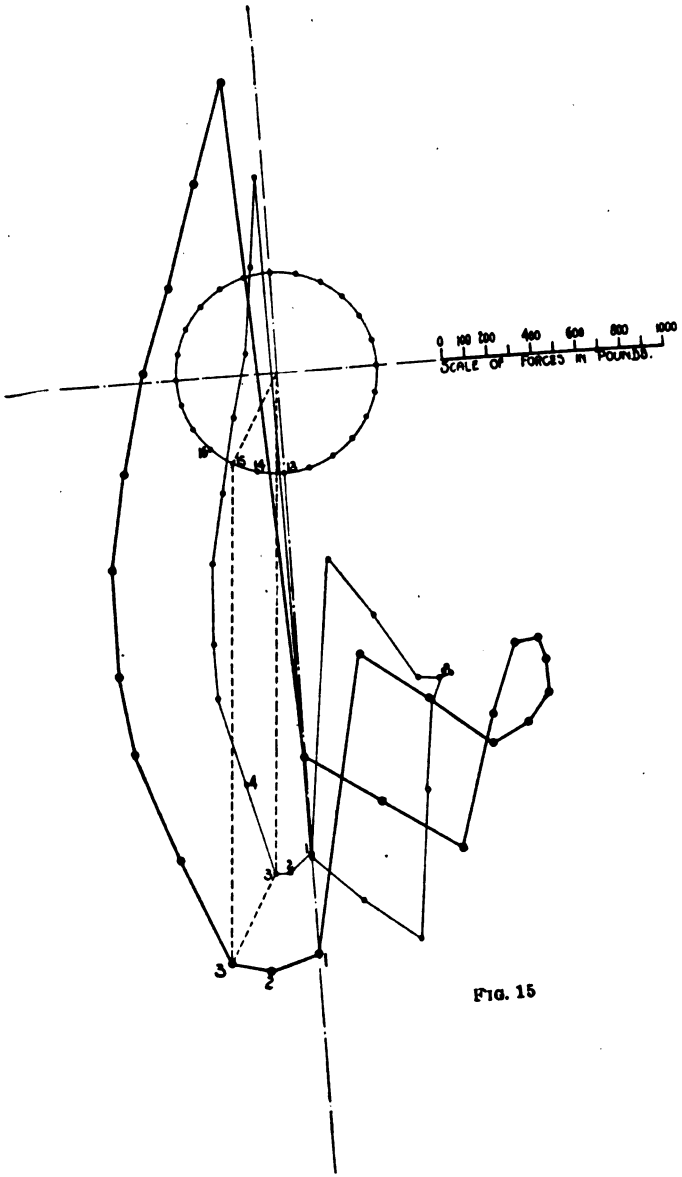


FIG. 15

Digitized by Google

of the crankpins. Consequently crankpins II and IV are subject to a twisting moment of

$$3070 \times 6\tfrac{3}{4} = 20{,}700 \text{ in-lb.}$$

The elastic limit of the crankshaft material may be taken as 80,000 lb. per sq. in. The factor of safety desired is 10. When denoting by d the diameter of the crankpin we have the following equation:

$$20{,}700 = \frac{\pi}{16} \times d^3 \times \frac{80{,}000}{10}$$

Hence $d^3 = 13.18$ or $= d = 2.36$ say $2\tfrac{3}{8}$

Comparison of Results

Let us now compare our results with others advanced by a highly-esteemed authority. This authority states that "The average lengths for the three main bearings, taking the length of the connecting-rod big-end bearing as 1, are 1.21 for the front, 1.17 for the middle and 1.48 for the rear."

The reason that these results deviate considerably from the former is that they have been arrived at by measuring the bearings of a number of engines. It is a fact that of the engines measured only one or a few were nearest to the ideal. The influence of the greater amount of data not as good qualified results very much in the fashion of the distiller's formula: ½ gal. wine + ½ gal. water = 1 gal. of whatever is ordered.

Another rule of thumb reads that the crankpin diameter should be $0.4 \times b + \tfrac{1}{4}$ in. With this formula we would obtain for our engine a diameter of 2.05 in. By substituting this in our equation for d we can determine the factor of safety F. It is

$$20{,}700 = \frac{\pi}{16} \times 2.05^3 \times \frac{80{,}000}{F} \text{ or } F = 6.5$$

This is obviously too small for a part as important as the crankshaft.

The Discussion

David Fergusson:—The examples given by Mr. Burkhardt are very important in automotive engineering. There is a tendency among some manufacturers of motor trucks to abandon radius rods and torque rods. In following Mr. Burkhardt's reasoning closely we can see wherein designers are likely to err when trying to

Digitized by Google

secure both propulsive effort and torque through the springs, thereby eliminating radius rods and torque rod. They must put extra weight into the springs to enable them to perform these two additional functions, and it is questionable policy to make a flexible member such as a spring perform the duty of a rigid member such as the conventional torque rod, especially as more weight must be added to the springs than is saved through the elimination of the torque rod.

There is great looseness of method in the design of motor cars and trucks, and faulty construction is in some cases due to the extreme haste with which these vehicles are put on paper and immediately afterward into production. Many laws of mechanics are lost sight of entirely, and we sometimes find a draftsman applying well-known laws without adequate knowledge of them. In one case recently, the fact that a hollow round shaft is stronger than a solid round shaft, for the same weight, was misconstrued by a would-be engineer, who recommended drilling a hole in a shaft that had proved to be weak to strengthen it, without changing its outside diameter.

There are cars and trucks constructed with the commonly termed Hotchkiss drive; that is, they do not make use of either radius rods or a torque rod. The apparent success of these may be due to the fact that all successful vehicles have a certain factor of safety in their parts, over what is necessary to take care of the load. It is this factor of safety that redeems many faulty constructions. The designer figures on a factor of safety of, say, 5. If his premises are wrong he may have only half of this, and while his truck may run satisfactorily in certain lines of work, it will never withstand the abuse that a truck having the full factor of safety would, and its life will be much shorter. Such a truck may give some degree of satisfaction if never loaded to its full capacity, or if never used on hilly roads. On the other hand, if used under severe conditions, it might break down and cause a fatal accident.

It is very essential that the full factor of safety be maintained. Whether this should be five or ten times the working load depends upon the work the part must perform, and this varies in the opinion of different engineers. Again, the value of the factor of safety depends on whether it is taken in connection with the elastic limit or the ultimate breaking strength of the

Digitized by Google

material. The best construction, from an engineering point of view, is that which gives the highest factor of safety with the least amount of material, and I believe that a motor truck should have both radius rods and a torque rod, or their equivalent.

In regard to crankshaft bearings, as Mr. Burkhardt has shown, examples taken from practice are often misleading. In many cases the bearings are almost twice as long as they should be, and the whole engine could be shortened up and thereby lightened, and at the same time stiffened. In other cases the bearings are too short, resulting in undue wear and necessitating frequent repairs. It is certainly good engineering to have those bearings properly proportioned, and so make the best use of the materials employed; otherwise we are not using proper methods of design.

MR. BURKHARDT:—I must agree with what Mr. Fergusson has said of the apparent success of vehicles embodying the Hotchkiss drive. The London omnibuses have no torque or radius rods and yet are doing their proper work day-in and day-out; but I must call attention to the fact that these vehicles are not encountering as many obstructions as, say, a contractor's truck. The omnibus can have springs designed to suit city pavements; the truck must be a good running vehicle whether it is carrying a light load of eggs or a 50 per cent overload on poor roads. In order that springs shall stand up under all kinds of loads we must maintain a definite factor of safety.

The deflection of the springs is a direct function of the load on the truck. With the Hotchkiss drive we must provide for much extra load, and we dare not exceed with this combined load the safe load on the springs. A spring resilient enough to carry a light load of eggs safely would be unsuitable for carrying a heavy load on bad roads, and a spring stiff enough to carry a heavy load over bad roads would be unsatisfactory for carrying the lighter load. The safe speed of motor vehicles is a direct function of their suspension; hence vehicles with radius and torque rods can be operated at higher speed than those without these useful members.

ROBERT W. CUNDALL:—I wonder if there is a force that Mr. Burkhardt has not taken into account in his illustrations which causes strain on bearings? How does the bearing unit pressure compare with the breaking stress of the shaft? In an engine, are large bearings

Digitized by Google

provided to give strength or to sustain pressure rather than stresses?

MR. BURKHARDT:—No important forces have been neglected in the investigation. Bearing loads are important. We can, however, as emphasized in the paper, determine the shaft diameter so that a certain fiber stress shall not be exceeded. Then we can lengthen the bearing until a certain specific bearing pressure is attained. Another point which needs mention is that the life of a bearing is a function of pressure and velocity. For this reason it is best to keep the diameter small. On the other hand, large diameters stiffen the shaft and reduce vibrations. I spoke of a factor of safety of 10. This factor is considered good practice.

E. T. LARKIN:—Regarding the crankshaft, we may enter into diverse calculations and still obtain a bearing so short that it will not maintain lubrication under the heat conditions met in a gas engine. It is necessary to have a longer bearing than the calculations show to maintain proper oil films. I have found cases where it proved to be better to provide three large bearings than five small ones on a crankshaft.

MR. BURKHARDT:—A three-bearing shaft is quite satisfactory for low speeds. For higher speeds the five-bearing shaft is more satisfactory, because the deflection of a shaft causes vibrations. Both are considerably reduced by shortening the distance between the bearings.

The front end of a motor vehicle has a tendency to leave the ground when the vehicle is proceeding forward, not backward. If we attach a drawbar high enough on the chassis, the front end will rise, not the rear end. If a spring is flat when loaded with, say, 3500 lb. at each end, it will assume a convex curvature the moment an additional load is imposed on it. This is bound to take place.

W. M. CORSE:—Tractors have a decided tendency to rear on their hind wheels and overturn backward.

MR. BURKHARDT:—This certainly is the case. A device designed for a popular tractor to prevent it from overturning is being put on the market.

F. W. DAVIS:—It is usually very poor practice to assume that the average design is ideal. The matter of bearing sizes is one that has been left to arbitrary methods. The practice is to add the bearing lengths, divide by the number of engines, take the average, and assume that the result is correct. The manufacturer of trucks

Digitized by Google

is constantly studying the details of design being produced at the present time, but we must bear in mind that present design still needs a great deal of study to produce the most economical results. Trucks should operate 20,000 or 30,000 miles before being taken down and overhauled, and after being thoroughly overhauled should be good for 20,000 or 30,000 miles more. This can be accomplished only by having the design right and the parts properly made and fitted in the first place.

Digitized by Google

CLEVELAND SECTION PAPERS

CORRECT LOCATION OF BRAKE LEVERS

By Walter C Baker[1]

BRAKE trouble is often only faulty brake-rod location. In the Hotchkiss drive unless the rear brake-rod center is located on the transverse axis, about which all rear-axle torque takes place, and the front brake-rod center lies on the axis which most closely approximates the center of the curve along which the torque axis moves relative to the frame, faulty brake action will result. The most effective way to locate a brake-rod is by a gage, two applications of which are shown in the figures, one to correct front center height and the other to correct the length of rod. The gage consists of graduated rods which, together with a dial indicator, are put in the place of the brake-rod and held by special clamps.

The axle and springs are put through approximately normal action independently, and any tendency of the rod to elongate or shorten is indicated on the dial. The figures show how, for various points, such changes in length might take place. Successive readings are taken, changing the front or rear center as the springs or axle are moved respectively, until no movement of the indicator is shown. Due to features of chassis construction, it is often not possible to locate the centers accurately. Then, a close approximation usually reduces the trouble to a minimum and to a point at which trouble ceases to be noticeable.

Brakes hitherto entirely satisfactory have caused trouble as manufacturers have altered their designs from, say, one using a torque member to the Hotchkiss drive, or when the spring has been moved from a position above the axle to one below it. The trouble is usually attributed to the brakes and it seems necessary to devise some means of demonstrating that the difficulty is not with the brakes themselves but with the manner in which they are hitched up. In the discussion which follows I shall attempt to show what generally causes the trouble in braking action and that this may be reme-

[1]Consulting engineer, Standard Parts Co., Cleveland, Ohio.

Digitized by Google

died by simply changing the rods and their locations. It is believed that an analysis of braking action will be of great interest to engineers connected with the design and production of automobiles.

In the design of both passenger and commercial motor vehicles, employing what is known as the Hotchkiss drive, engineers have in many cases either failed to consider rods, levers and braking action, or have considered these insufficiently or incorrectly. The result has been that in a great many cases the brakes have been either inadequate or too severe. It is almost universally true that while at some one point and in one direction the brakes operate perfectly, at most other points or in the opposite direction the braking action is poor.

Brake-Rod Gage

Many annoying features characterize the brake that is incorrectly connected, in addition to the danger that always exists while driving. In all cases redesigning the brake-rods and levers correctly will eliminate these disagreeable features, and to enable one to locate these centers correctly, I have designed and had constructed a brake-rod gage.

It is not commonly known that somewhere in or near the rear axle, there exists a transverse axis about which all torque action of this axle takes place. When a torque member is used, this axis is usually forced to coincide with the center of the rear wheels and axle. When no torque member is used, as is the case with the Hotchkiss drive, the torque axis lies outside the axis of the rear wheels, and for ideal action of the brakes the rear brake-rod center should lie on this transverse torque axis, while the front brake-rod center should be placed at a point which most closely approximates the center of the curve through which this torque axis moves relatively to the frame when, due to load and road conditions, the car is in various positions above the axle.

To locate these points correctly by graphical means or calculation, with the information we have at present, is an impossible task. They are more nearly located by tests while the car is in action, and to insure correct results a brake-rod gage of some sort should be used. The gage I have been using consists of several interchangeable rods of various lengths, graduated to inches and operating through a dial gage which indicates any lengthening or shortening of the rods, when placed by conven-

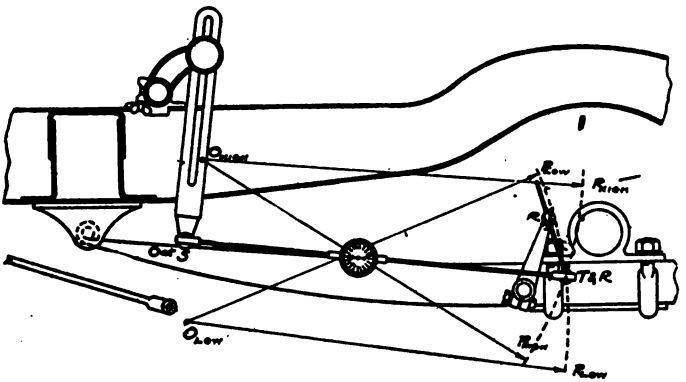
Digitized by Google

ient attachments in the position of the brake-rods themselves.

How the Gage Is Used

The cause and effect of the elongation or shortening of the rods are explained in the discussion which follows.

Let us denote the torque axis by *T*. This is the axis about which all torque action takes place while it in itself remains stationary with reference to the rear axle. It is clear, then, that if the rear brake-rod center were fixed on this axis, then so far as torque is concerned there would be practically no action on the brakes themselves due to the fact that the point of application of braking force is nearly stationary.



A Case Where the Front Brake-Rod Center and the Spring Axis Do Not Coincide

Let us assume, however, that the rear brake-rod center is not correctly placed, and that it lies outside the torque axis on some axis such as *R*. Then there must be some movement of *R* about *T* when torque action takes place.

Suppose we are looking from the left side with the car traveling forward; the rear brake-rod center *R* will move in a counterclockwise direction when the brakes are applied. If the rear brake-rod center *R* happens to be above the torque axis *T*, such motion will tend to shorten the distance between *R* and the front brake-rod center *O*. If the rear center *R* is below the torque axis *T*, the distance between *R* and front rod center *O* will tend to be greater. But since *R* and *O* are rigidly connected by a rod, *O* is forced to move with *R*, and consequently moves forward

Digitized by Google

or backward, depending on the relative position of the rear rod center *R* with reference to the torque axis *T*. Of course whatever tendency there may be to shorten or lengthen the pull rod when the car travels forward, this is reversed when the car travels backward and brakes are applied.

With the brake-rod moving forward and backward in this manner, one of two things must take place. Either there is a corresponding movement of the brake pedal and hand lever, multiplied by the leverage ratio, or the brake levers of the rear axle are being operated upon independently of any voluntary action of the driver. Very often in cases of extreme movement of the rod, motion of the car in one direction automatically applies the brakes, or makes them grab severely, whereas motion in the reverse direction makes it almost impossible to apply the brakes, due to the pedal in its extremes being in contact with the floor-board, thus limiting the radius of action.

When the rear brake-rod center *R* lies either in front of or behind the torque axis *T*, on a line from the front rod center *O* to *T*, the action due to torque is usually very good, because what motion there may be is chiefly up and down and does not materially change the distance between the rear and front brake-rod centers. This motion would of course increase as the distance of the rear center *R* from the torque axis increased and when this became very great the change in the distance between *R* and the front center *O* would be considerable.

It is clear, then, that the only point at which there would be practically no motion of the rear center is at the torque axis *T*, and a point on this axis is the ideal location of the rear brake-rod center *R*.

To locate the torque axis *T*, let us employ the brake-rod gage, mounted either vertically or horizontally, the latter being the mounting shown. After the gage is mounted, a torque effort is exerted on the axle by some means. In this case, to show the action clearly, I have attached a rod to what would correspond to the axle housing and by displacing this rod, a torque effort is exerted sufficient for our purpose.

With the front center *O* of the gage-rod fixed, any movement on the part of the rear center will be shown on the dial indicator, until adjustments are made which will place this point so that extreme movements in torque will have the same indicator readings. Having done this with the gage horizontal, it is then placed in a vertical

Digitized by Google

position with the rear center still at the point just found. The locating process is then repeated. In the first case the rear brake-rod center was confined to a horizontal plane containing the torque axis *T*, and in the second case, while not moving out of this horizontal plane, it is further confined to a vertical plane containing *T*. The rear center is thus forced to lie at the intersection of these two planes, or on the torque axis *T*.

We have then determined the best position for the rear brake-rod center. Very often it is not possible to actually reach this point, due to the position of other parts. When this is the case, the next best thing is to place it as near the actual torque center as possible and in line with the torque center and the correct position for the front brake-rod center *O*, with normal load on the springs. To do this the spring axis *S* must first be located, before which we must consider the action of the springs.

Effect of Load and Road Conditions

When the car assumes various positions above the axle due to load and road conditions, it deflects or flattens the springs, as the case may be, and as they deflect or flatten the distance from the front eye to the spring seat shortens or lengthens respectively. Since the axis of the front spring eye is held rigidly in position as regards the frame, the axle and all points on the axle member describe curves relative to the frame when successive positions are assumed on the frame above the axle. The curve that any one point describes is not an arc of a circle because of the lengthening effect of the spring as it flattens. The curve is one which resembles an epicycloid.

With the rear center of the brake-rod *R* on the torque axis *T*, it is ideal for the front end to be at the center of a circle which most nearly approximates the curve described by *T*. This will maintain a very nearly uniform distance between the torque axis *T* and the front center *O*, and there will be practically no effort exerted to move the pedal or operate the brakes, independent of voluntary action of the driver.

If, however, the front brake-rod center *O* does not lie on the spring axis *S*, we have a condition similar to that shown. Let us assume that under normal load the condition is as at *T*. With the front center at *O* instead of *S*, the front center *O* will be forced to move in a circle about the countershaft, a distance equal to the difference, at any

Digitized by Google

given position, between the arc described by the torque axis and the circular arc described by the rear center about the front rod center *O* as a center. If *O* is above the spring axis or too high, a heavy load will have a tendency to loosen the brakes making it impossible for the operator to apply the brakes, if the front center is very high. Or, often, when it is possible to set the brakes with the load on, they will be so firmly set that it will be impossible to release them when the load is removed. This can easily be seen from the drawing. Under full load, the difference between the curves is such as to throw the front rod center forward, while at the check position in rebound the difference is such as to pull it back. When the front center is too low, as in this case, the effects are just the opposite. When a load is applied the brakes become set and when it is removed they are loosened. Often, in such a construction, when the brakes are set and a load is put on it becomes impossible to release the brakes without removing the load; or when it is possible to set the brakes after the load is on, the brakes are loose when the load is removed.

Error Produced by Incorrect Rod Length

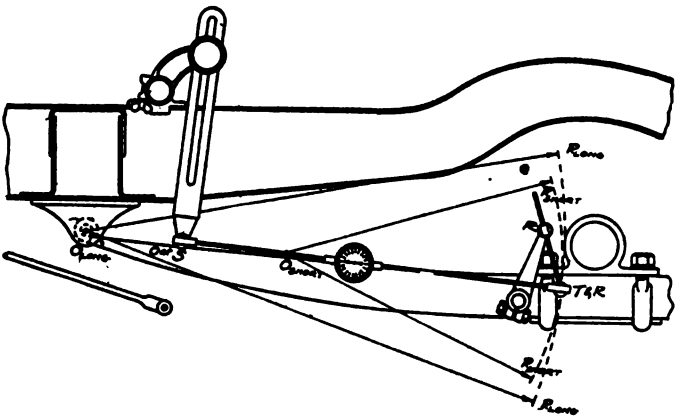
Further than this, there is an error due simply to incorrect length of rod. If the front rod center *O* is behind the spring axis *S*, as shown, thus making the rod too short, the application of a full load has a tendency to tighten the brakes, because the difference between the curves at the extreme is such that the rear center is pulled forward. When the front rod center is in front of the spring axis *S*, thus making the rod too long, the tendency is to loosen the brakes, because the difference between the curves in this case is such as to push the rear center back.

Usually there would, of course, be no real action upon the brakes as long as the pedal movement was unrestricted, because such errors would be absorbed by the pedal movement until the full sweep of the pedal had been reached. Designers have many times used a slotted rod or clevis to overcome this, but this movement is often so great as to be objectionable, as well as a feature of reduced safety when quick and positive action of the brakes is required. However, the effect is much less when a rod is simply too short or too long, than when *O* is too high or too low.

Digitized by Google

Now to locate the correct position of the front brake-rod center O, with the gage, we proceed as follows:

Assuming that the correct position of the rear brake-rod center T has been determined, we fix it firmly by the necessary attachments. We then apply the load, making the frame assume various positions above the axle, or for an easier demonstration, making the axle assume



TYPICAL CASE OF THE BRAKE-ROD BEING EITHER TOO SHORT OR TOO LONG DUE TO THE INCORRECT LOCATION OF THE FRONT CENTER

various positions under the frame. The curve described by the torque axis T not being an arc of a circle, there are only three points which will be common to the arc through T at normal load about the spring axis S as a center. In other words, there are only three positions of the car above the axle where the brake action will be perfect, although if the front center O be placed at the spring axis S, the error at all other points will be reduced to a minimum, usually not exceeding a few thousandths of an inch, and will not be noticeable in action. For best results these points of perfect action should be chosen, first at normal load and secondly at points about three-fourths of the total movement of the spring either way from normal. In other words, the two points should be located when the load is three-fourths the difference between normal and full-load extreme position and three-fourths the difference between normal and no-load extreme position, respectively.

As the load is applied readings are taken on the dial

Digitized by Google

indicator at the three points just mentioned, and are recorded in hundredths of an inch. When the three points have been reached, the records taken will indicate the relative position of the spring center *S* from the front brake-rod center *O*. For instance, suppose the front brake-rod center *O* is too high, O moves in an arc about the countershaft *C*. The rear brake-rod center *R* tends to move in an arc about the front center *O*, but it actually moves along the curve described by the torque axis *T*, relative to the frame. Since under full load the difference between these curves is such as to push the rod forward and since in the gage the front brake-rod center is held stationary and the rod merely allowed to telescope, the change that takes place will be indicated by the dial gage readings. Under full load the rod will shorten and under no load or at check position it will lengthen.

Suppose that at normal load the reading on the dial is 0.52 in. and at full load it has increased to 0.71 in. and finally at no load or check position, due to the rod lengthening, it has decreased to 0.36 in. Since the check position reading 0.36 in. is less than the full load reading 0.71 in. it indicates that the difference between the curves at check position was such as to pull the rod backward and consequently shows that the front brake-rod center is too high. Therefore, when the check position reading is less than the full-load reading the front brake-rod center is too high, and if the full-load reading is less than the check position reading, the front brake-rod center is too low. If the front brake-rod center *O* is at the correct height the two readings will be the same, although both may be wrong for correct rod length.

If the front brake-rod center *O* were on a circular arc described about the torque center *T*, and also passing through the spring center *S*, the rod would be of the correct length, regardless of the distance of the front center above or below the spring center, because its length would always be equal to the distance between the torque center and spring center, which is always correct for rod length. In this case an arc about the front brake-rod center *O*, which passed through the torque center *T* under normal load, would reach just as far beyond the curve described by *T* at one extreme as it would fall short of it at the other. In that case the dial readings would show that the differences between each of the extreme rod lengths and the length at normal load, were the same; as for instance, full load 0.67 in., normal 0.50 in. and check position 0.33

Digitized by Google

in. The differences between each of the extreme position readings and the normal reading are the same, or the sum of the extremes is equal to twice the normal. The latter method of handling the readings is the correct one, because if the rod were too short or too long but at the correct height, the difference between the extreme readings and normal reading might be the same in number of spaces passed over, but one would be a positive difference and the other a negative. This can readily be detected by simply adding the extremes and comparing the sum with twice the normal. If the sum of the extremes exceeds twice the normal the rod is too long; if it be less, the rod is too short. Thus with a single set of readings we may determine our error in two directions, which enables us to make adjustments in two directions accordingly, after which we take a second set of readings.

After the gage has been used several times it becomes an easy matter to approximate the correct amount of adjustment needed. Usually a sufficiently correct location of the front brake-rod center can be accomplished in two or three readings.

When the gage was first constructed, a set of formulas was worked out which gave the correct amounts of adjustment necessary to place the front rod center at the correct position. But these formulas were rather complex and employed constants depending on the nature of the spring, and their solution usually required considerable time. After several comparative trials, it was discovered that an adjustment of the apparatus usually required less time and was more apt to be free from errors than the solution of the formulas. Consequently the formulas have been discarded in favor of simple adjustments of the apparatus, and to facilitate matters further, easy means of adjustment have been provided on the gage. It is not a difficult matter to have practically perfectly acting brakes. When these centers are correctly located for any of the various styles or designs of chassis, there will be no further trouble with brakes due to spring action on rough roads or to varying loads and Hotchkiss drive.

THE DISCUSSION

MR. BAKER:—A common error is to make a brake-rod connections with the levers located with the springs above the axle, and then to use the same arrangement of levers by putting the springs below the axle. This

Digitized by Google

causes trouble at once. The levers must go down with the spring and on most constructions it is hard to place the brakeshaft in the correct location on the rear axle without interfering with the springs or the frame. If we put the springs below this center, the torque center must go down and follow the springs below the axle, and the levers must go down with it. This means that the front center which should be at the spring axis will go down at the same time. There is one correct position only on an axle for that rear center and this is at the torque axis, and one correct center only for the front and this is at the spring axis. Anything else is an error and these errors are directly proportional to the distance of removal from the centers. I have had men insist that this could not be true, and have made a brake-rod connection to show that it is true. You can find no other two centers that will be right for that hitch-up. As soon as you move it in any direction you have an error from the torque or spring action.

With a torque rod you can compromise the torque movement with the spring movement because usually the torque rod makes a fixed torque action with the spring action, *i.e.* if you lower the frame on its springs 2 in. the front end of the torque rod goes down and rises and falls with the spring.

I do not know of any part of an automobile which has had less study, and never drive a car without settling in my mind approximately the errors, if any, in the location of the brake levers. By applying the brakes with the car standing and noting what effort is necessary to move the brake pedal, say one-half of full travel, then doing it again when the car is in motion, it is possible to determine if the rear center is much above or below the torque axis. If sufficiently above, the torque action increases the pedal movement to the full travel without adequate braking. With the car going backward this arrangement would undoubtedly cause the brakes to grab. If the rear center is below the torque axis the conditions will be reversed. In practice I believe it is better to place the rear center slightly below the torque axis.

I measured up the Class B Government truck, putting sufficient weight on the chassis to give our extreme spring movement and attaching a hoist so as to get our three positions; doing the same thing with a truck that I have done here.

Digitized by Google

A MEMBER:—I am surprised to hear you say that the torque axis should be a little below rather than above. I remember one case where it was placed too low, and when the brakes were applied the car jumped along.

MR. BAKER:—There are some brakes that are almost hoists. In applying brakes, if you place the rear center a trifle below the torque axis you assist the braking when going ahead, but you decrease it when going backward.

W. R. STRICKLAND:—Two years and a half ago, with Mr. Baker's assistance, we found that by locating the centers in accordance with his formula we could go forward or backward without any brake grabbing.

MR. BAKER:—I have found it absolutely necessary to make a brake-rod gage to demonstrate these points. When the Hotchkiss drive was first used it seemed almost impossible to convince anyone that the same brakes were just as good as before. When the springs were placed below the axle in these cars to get close to the ground the trouble began, and in many cases it was found impossible to keep the spring there and the old construction was resumed. There was trouble because the centers also were not placed below the axle. Find the axis and get the lever centers at the points I have described and you can get a perfectly working brake under all conditions.

A MEMBER:—How does the Franklin succeed with a flexible frame?

MR. BAKER:—Their car has considerable travel in the foot pedal and hand lever, and the motion of these is parallel with it. They use a long connecting-rod instead of a radius rod, and when they apply the brake going ahead the tendency is for the rear axle to move backward. That tends to tighten the brake.

A MEMBER:—What action is there with torque tube construction such as used in the Fiat?

MR. BAKER:—If the spring pads are free the torque axis is at the center of the axle and the best length of rod would be equal to the length of the radius rod, in this case the distance from the center of the universal-joint to the center of the axle. With a torque tube, any error of rear center location usually will not cause any noticable disturbance in brake action. The greatest errors would come from spring action, when the front center of the rod is too high or too low, not at the spring axis. From measurements I have made on a number of cars it is comparatively easy to approximate the correct location of rod centers. One will notice that a number of

Digitized by Google

Hotchkiss drives are in use on which little attention has been given to the correct location of rear centers. When the spring is placed below the axle the rear center should be lowered the same amount having the same location with reference to the spring as when above the axle.

A MEMBER:—Do you not think that the bad hitch-ups on the chassis are due to the axle manufacturers?

MR. BAKER:—In many cases, when the Hotchkiss drive first came into use, I wished to change the location of the rear center. The car manufacturers claimed they had used axles by the thousands, had experienced no trouble in braking with their present location of centers, and did not wish to make any change as it would necessitate a considerable expense. There is no possibility of making a standard axle as to location of rear rod center with the Hotchkiss drive, unless the main leaf of the spring always occupies the same relative position as to the axle center. I found it necessary to make a gage to prove that most of our trouble with the brakes was due to errors in location of brake-rod centers. I remember using a car with Hotchkiss drive in which the agent said they were having much trouble with the brakes. When the car was standing little pedal movement was possible in applying the brakes which were adjusted very closely. By applying the brakes with the car in motion it was possible to push the pedal which had an unusually long travel, to the floor, the torque action releasing the brake in proportion to the pedal movement. When I tried going backward a sudden application of the brakes broke one of the rods. Instead of torque action releasing the brake the reverse condition broke the rod. From this I assured him that the rear center was much too high.

A MEMBER:—At the automobile shows there are as many cars with springs under the axles that have the brake levers sticking up as there are with brake levers below.

MR. BAKER:—It takes considerable redesigning to move all the countershafts underneath a car and change the length of the lever. A manufacturer of automobiles prefers to say, "You fix your rear axle so that it will hitch up with our arrangement of levers." He arranges it so that although the spring is below, it hitches up with the same original setting, and that is where the trouble lies. It cannot be done successfully.

Digitized by Google

CONDITIONS IN THE AUTOMOTIVE INDUSTRY ABROAD

By David Beecroft[1]

THE author's observations cover the period immediately following the war when, as a member of a party of representative guests of the British and French governments, he toured England, meeting Government officials and talking on industrial matters; visited Scotland's shipbuilding and coal areas; viewed the battle area, aircraft, automobile and tractor factories in France; and traveled in Italy, later returning to England to inspect factories, conduct investigations and review Government activities.

The enormous expansion of the automotive industry factories of the Allied nations is emphasized and their organization and methods briefly described, with running comment on comparative practice in the United States. Factory production methods in England are mentioned, as well as working conditions and welfare work there.

Considerable information relating to post-war automobile designs and to motor-truck and tractor practice is given. A belief that there should be much international standardization is expressed. Universal traffic rules, standard width of gage or track and the fuel question are touched upon and the main features of the airplane industry and its future tendencies are described. Solid tire mileage on London streets is mentioned, the present tendency of the motorcycle industry is indicated and the foreign demand for small, light, cheap automobiles is stated. Comparative statements regarding present European and American practice are frequent.

The observations I shall make cover the period just after the war. Our party was not fortunate enough to be over there during the war. I should perhaps explain the reason for making this trip. Fifteen of us were guests of the British Government. During the war,

[1]Managing editor, Class Journal Publishing Co., New York City.

Digitized by Google

as you know, the natural channels of communication between the two countries had been broken off and the censorship had really created a barrier between France, England, Italy and America, so far as the exchange of information was concerned. Previous to the war we had well-established channels of communication between our Allies and ourselves. It was with the intention of breaking this barrier down that our party was one of many that were invited and taken over there, not only to see the battle area, but everything else we wanted to see. We had the distinction of going over the battle area after the fighting had ceased. Parties from all of the other neutral and allied countries of the world had just preceded us; there had been still others from Africa, Asia and South America. Theirs was a great organization, one we were not familiar with, this propaganda movement to let the world know what had taken place. We who went over would not be doing our part if we did not do our very best here at home to let as many people as possible know what we saw. If we could all be moved over there and see, it would be the means of binding the whole world more closely together, a means of interpreting what has happened since 1914. It is only after one gets there and talks to people that one realizes how little we have known and what a barrier the censor was during the entire war period.

We reached London a few days before the armistice was signed, and spent two weeks going over England, meeting Government officials and talking of industrial matters. We went through Scotland's shipbuilding and coal areas, and then back to London and over to the front for 10 days, as guests of France. We did not get over all the front, but traveled as much as 250 miles a day through the battle area all the time. We went to Italy for a week. When we came back to France, we visited the aircraft, automobile and tractor factories. In England later we inspected the factories, carried on investigations and looked into the matter of Government activities.

The Factories of the Allied Nations

This is not to be an engineering talk; that is out of the question. It is going to be a mixture of what we saw in the factories and on the battle fronts; of information we got by talking to the heads of departments, and to officers in the Army, in the Ordnance Department, in

Digitized by Google

the Navy and of transports and various other matters. I shall begin with the factories. We have all heard a great deal about them. I had been through perhaps fifty factories in France and England previous to the war and I was amazed at the expansion. Take the Renault factory in France as an illustration. Previous to the war they employed 5000 workers; in December there were 23,000 housed, and there were three and four-story buildings half completed. You could tell by the layout that they had had no conception of what the expansion was going to be. The plant was not arranged symmetrically. They would start a three-story building, but long before it could be completed their conception had been outgrown. Several miles away they had just finished a huge airplane factory. The whole place was a marvel of activity. Probably 50 to 60 per cent of the workers were women, busy on tanks, tractors, trucks, guns and various other things. We saw them in the tank factory assembling twenty tanks a day by the moving-chain method, and not far away there was a large testing ground. There was a huge building given over to the manufacture of guns as large as 8 in. in diameter, all the work on them, breeches, sights, etc., being done there. Another factory made the carriages for these guns. The French soon realized the need of motor apparatus for drawing the guns. It was useless to adhere to the old-style wheel, so all large guns are mounted on truck chassis with small wheels and rubber tires. They were moving guns at a speed of 25 miles per hr. and we could not but feel that if we ever have another war the automobile truck will be supplied for all the ordnance work.

We saw the great airplane factories making engines. There were the same engine assemblies that you see here in Cleveland, crankcases on stands, women doing every bit of the assembly work on the engines. Throughout the factory there were evidences of organization, but not the same rate of progression that we see in our factories. The reason seemed to be that they could not carry on both expansion and organization at the same pace. The Government was forcing them. In the truck department the assembly methods were not as modern as ours.

We went into the Gnome plant. Its number of employes had increased from 500 to 5000. A great foundry was just being put into operation. Close by was a forge shop. Not far away were great additions to the plant.

Digitized by Google

We saw many indications that they were looking ahead. The Gnome people seem to be getting away from the rotary engine somewhat.

The Salmson engine has a great reputation in France for being the most reliable in aviation work. Our forces used the Salmson plane for artillery work. The Gnome organization was impressed with the Salmson engine and we saw the drawings for a twenty-cylinder four-cycle 800-hp. Gnome engine. They are going ahead on that for commercial use.

Another French factory, Lorraine-Dietrich, has been spending most of its time building eight and twelve-cylinder V-type airplane engines. We saw there a twenty-five cylinder engine not yet completed; it was of W-type and great development is expected in it for aircraft work.

Take one of the other plants, the Fiat Co. of Italy. I did not know how much the Fiat had grown. There were 50,000 workers in the organization when we saw it; about 23,000 in one factory assembling cars, trucks and tractors of various types, making airplane engines and carrying on other work. Then there were the steel foundries in which they used electric power only. In another part of the city was the huge forge shop just completed and most modernly laid out. Nothing in this country is any better. Nearby was a half-completed large four-story building for truck assembling work, and along the railroad tracks was a stretch of ½ mile of material arranged row upon row, and stacks of aluminum and copper. The amount of material they had on hand was amazing. Fiat told us that they had delivered about 62,000 vehicles, trucks and motor cars to the Allies. Yards were filled with trucks. The assembly methods were not worked out as well as ours. I shall speak in general on that later. Electric power is obtained cheaply and is used for everything. While coal is expensive in Italy, that does not necessarily affect the whole manufacturing proposition.

The Rolls-Royce factory previous to the war had 3000 employes; it now has 8000. Rolls-Royce has been working since the start of the war on airplane engines and will be working on these for several months yet.

I want to remind you that all the enlargements mentioned are permanent brick and reinforced-concrete buildings, the same as ours. Some are one-story, others three

Digitized by Google

and four stories high. There are rows upon rows of new machinery, a great deal of ours as well as of their own. In the Fiat and in French and British factories they have built their own machinery.

We went into another factory at Manchester. It has been making cars most of the time since the war started, the reason being that when the Royal Air Force was organized light motor trucks were wanted and the Crossley design was selected. At the start of the war it had 100 employes and underwent a great expansion. Then the Crossley plant was building fifty vehicles a month; a month later it was building 250. It had no great system in assembling, but was getting ready to renovate. It had been held back by the Government, was short of help, and its engineers were generally taken off for other work. The six-cylinder, vertical Beardmore airplane engine which has been used a great deal was being built, as well as the British A. B. C. eight-cylinder air-cooled, radial-type engine; production was started in November on the "dragon-fly" engine. We were driven 3 miles to the new airplane factory, not long before a potato patch. It covered 23 acres of ground, a modern factory with cement floors, sawtooth roof construction, forced ventilation and every possible convenience. Here were rooms where DH-10 planes with two engines were assembled, in rows of twenty and thirty. Outside was a great testing and flying field, and across the road another test field.

The British factories had other surprises for us. The Austin Co. is located 10 miles out of Birmingham. It employed 2000 before the war and 22,000 at the close. During the war airplanes, airplane engines, armored cars, motor trucks, cars and great quantities of ammunition were manufactured. It was this company that demonstrated to England what production in shells meant. I think it was making the 4.5-in. shell, but at any rate the price was $62 each, and after rigging up for production it was sold for $31 each, just half. Many other British manufacturers did not think this possible. The matter came up in the House of Commons, and Austin was obliged to demonstrate that it was possible. Austin has a factory as complete as any ever developed. He has every facility, and being in the country, draws 50 per cent of his employes from Birmingham and the others from the surrounding towns and villages, having great fleets of motor buses to bring them in. There are canteens where the workers get lunches, etc.

Digitized by Google

The company operates grocery stores and has great agricultural areas where it grows its own produce. It has auditoriums for the benefit of the employes, with moving pictures and lectures, and three or four engineering organizations within the force, with special schools for the apprentices. who take 2 hr. off and go to school for a period of 6 months. There are Red Cross organizations and regular dormitories for the women to use at night, for if taken sick it would be inconvenient to send them home. The company has gone into every possible phase of welfare work. So it was everywhere we went. There was hardly a factory that had not been developed and increased in size from five to ten times, and let me remind you again, these factories are all modern.

Working Conditions in Factories

Now let us spend a little time on the subject of factory production. Labor in England went on a 48 hr. per week basis. Previous to that they worked from six in the morning to six at night, with an hour off for breakfast, an hour for luncheon and an hour at four for tea. We asked, "How much has production fallen off in the change from 54 to 48 hr.?" It seems that the number of chassis increased three per day on the 48-hr. basis. They had lowered the working time, but studied the assembling and improved the general spirit among the workers. England was face to face with that shorter week and went into the problems of production. They were all working during the war on a "cost-plus" basis, founded on efficiency, and they looked forward to increased efficiency and reduced costs just as soon as Nov. 11 passed. We arrived there at a time when production had not improved as it should have done. We did not see as many multiple-spindle machines as we have here. We did find a great improvement in dies and jigs, and great saving in the time of machining jobs. One job in machining a crankcase that had always taken 5 hr. had been brought down to 45 min. by improvements in jigs and tools. Even in factories where they were building cars they did not have the same line of progressive assembly of parts that we have here. They said they were doing as cheap machine work as we were doing here, but admitted that when they got into assembling they lost money. The fitters were bent on good work and would do good work only. When we got into the Manchester area

Digitized by Google

we seemed to run into a group of workmen who had caught the production idea. Improvement in factories was being much discussed in England, and manufacturers were moving up to Manchester, because of the better spirit shown by labor there.

I think it is a pretty correct conclusion that Europe has much progress to make in assembling, but is going to make it quickly. It was hard for us to understand what a controlled factory meant over there. Some were very badly disorganized; their engineers were taken away; they were compelled to sign an agreement they would not do any development work. Being tied down there was no incentive to go ahead on production plans; yet in every factory they are now asking for production men, and there is an opportunity for men who can make good in the production field. They have recognized the fact that to get the best out of a factory they must develop their production methods.

They have as good welfare work in all the factories, British, French and Italian, as we have here. They have doctors and nurses everywhere. Anybody having a scratch is compelled to go to the factory hospital. They have physical examinations of the men for fitness and look into their home life and see that homes are kept in good condition. I think that the large employment of women is responsible, to a considerable extent, for this new interest in the worker. They were able to get higher production with the women than with the men. Everywhere we went we were asked for better equipment. They want industrial and electric trucks for moving materials. It surprised us to see four or five workers pushing the trucks along. They had not been able to get the industrial trucks. Fiat received four after waiting for them for over 9 months. Very great use is made of the overhead monorail in factories, and in places small trolleys are kept running through the aisles.

They have given a greater amount of attention to ventilation than we have. Huge ventilators are used through which the air is exhausted, and good exhaust systems are attached to every saw in the woodworking departments. They have done a wonderful amount of work also in protecting the workers from machinery.

In some of the factories, particularly magneto plants, the lighting is noticeably good. Magneto manufacturing is an industry new to England, begun during the war. There is now a regular magneto organization with thir-

Digitized by Google

teen or fourteen factories in it. We were in one four-story brick building with sides of glass, where the lamps were brought down on the left side of the individual worker and there was no glare. The condenser tables had glass partitions. The seats for the women had adjustable foot-rests. The layout was perfect; I do not know where one could find anything better. We spent a half-day in one of the large machine-gun factories of the Birmingham Small Arms Co. in Birmingham, a four-story structure with two parallel buildings and connecting cross galleries. Here also was the same regularity of arrangement.

The use of an auditorium has become very general. They had taken up the movies and, of course, the films most used were about the war. It was by these films that the workers in the factories were kept in close touch with conditions at the front. They are now using films to show manufacturing processes in the same way that we are here.

Post-War Car Designs

We obtained much information on post-war models not yet out. For example, Fiat has a small four-cylinder type car, designed for quantity production. Renault has one, the price to be about $1,000. Crossley, the Austin Co. and several others each have one. By far the great majority, however, have not had an opportunity to start on new work. They have all gone into electric starting and lighting, however, and in many cases with their own apparatus. Renault and Fiat are doing this. They have some standardization work to do, to all appearances. There are twenty-three different battery makers in England, all using different standards and sizes, and it is the same with the car people as it formerly was over here. They are putting the batteries in most inaccessible positions. The starting motors are being mounted about as ours are and using the Bendix drive. It is a two-step affair, first engaging the pinion and next putting on the current. The generators are now belt driven, but it is intended to mount them integrally with the engine and drive through gears. The coming of the electric starting and lighting has started a tendency toward the valve-in-head engine. The real post-war models all have I-head engines. They admit that they got the inspiration from America, and particularly from aviation engine production. One thing that led to the

Digitized by Google

movement is the easy mounting of the engine generator. They are strong for accessibility; and they can get at both sides of the engine if they use this design.

Their new cars have the same high hood that ours have. This affords room for the I-head engine. They objected to this engine some years ago on account of noise. Since then much clever work has been done, and they feel that they can now get every part quiet except the drive. They intend using an overhead camshaft and are working to get it quiet. They were all very much taken with the I-head design in handling a rapid flow of gases. The speed of the gas can be doubled from the carbureter to the engine without cutting down the power. Small valves can be used.

Our cars receive a great deal of criticism. They say we sit on our cars while they sit in theirs, and when you ride in their cars you agree with them. We spent 10 days in different makes of European cars. They ride remarkably "easy". When the speed gets to 40 or 45 miles per hr., you do sit in their cars; the cushions do not hit you in the back. They go into that point to a great extent. We were in one factory where there was a skeleton with patterns of legs, arms and body cut out. They had studied the tension put on the different muscles when the back is in different positions. Their cushions are designed so the passenger can sit with the least possible strain on the muscles. I believe we could do a great deal along that line. Their cars are most comfortable and they are very low.

Motor Truck Design

I have been asked about the trucks in the war zone. There are two essential characteristics of trucks—ruggedness and accessibility. The truck was required to carry 100 per cent overload if necessary, but it had to be accessible, for there were times when in repairing a truck it was more bother to get at the part than to make the replacement.

With Europe coming back into the truck market, automobile trucks and tractors should be to a large extent international. There is great need for us to get together and standardize to make their use easier for owners. This is true also in the battery business, and they are very anxious to discuss it. We found Fiat making a certain type of battery with one single connection;

Digitized by Google

Renault building a different type and, as I have stated, twenty-three different types in England alone. Think of the money that is and will be tied up, and how difficult it will be to sell and give service in the other countries of the world. Batteries should be as interchangeable as gasoline or oil and tires as well. They are considering our tire sizes. They are anxious to reduce the number of tire sizes as much as possible to improve the merchandising.

We certainly have a problem ahead of us in our export trade. The world is tremendously big and wants automotive apparatus. There is going to be enough demand, more than all can supply. The biggest job is to make it as easy as possible to buy this apparatus, operate it and keep it in repair. There is no reason why France, Italy and America should set up their own standards in different parts of the world. We must remember that "characteristic" designs, individual preferences and little peculiarities in a car set up barriers and create sales resistance in India, Canada or Australia. Would it not be better for the manufacturers to talk these problems over as makers, and cooperate, rather than fight them out in the merchandising fields at the four corners of the earth? We are now preparing to build apparatus that is to go to all parts of the globe. Let us listen to the demands made from these different quarters and be reasonable in adopting suggestions.

In the war zone all drivers had to keep to the right side of the road. That impressed the British, for their rule of the road is the reverse. In Italy some cities have one rule and some another. It is expected that the Peace Conference will settle the rules of the air, and it would be well if the rules of the road could be standardized. If we had international road rules the cost of manufacture would be reduced to some extent and sales resistance on that point eliminated. Automobile manufacturers should get together and push on this point.

European nations should all build a standard width of gage or track. There was trouble before the war, for they built gages of 62 and 64 in. for certain countries. We are very glad to know that Fiat decided to build for export a 57-in. gage only. How much more fortunate for us that they are already building a 57-in. tread. There will be great manufacturing economy if all the nations can agree in this matter.

We should watch the fuel question. That is quite

Digitized by Google

serious. Gasoline in Paris was $1 per gal., in England 82 cents, in Norway and Sweden $2, in South Africa 90 cents, and in Australia 80 cents. It was 25 cents here. They think a great deal more of fuel economy abroad than we do, and the engineer in designing his job, whether car, truck or tractor, must give attention to it. We design our engines with America too much in mind. If we are going to spend big money on the foreign market, we must give attention to fuel economy. In Sweden it was almost impossible to get gasoline and they were using alcohol.

London has many steam trucks. Up to 1915 they were operating on steel tires, and after that on solid rubber tires. Over in the war zone we saw them everywhere. The fuel cost is about 50 per cent that of gasoline. In other places they have been developing still other types of vehicles. We found Italy asking for electric trucks, and one factory considering the manufacture of them. This suggests that there must be a good deal of variety in automotive apparatus over the entire world, and if we confine ourselves to one type of vehicle, say the gasoline type, we are not going to meet the entire field. Foreigners have stronger individualism than we have here; the individual is more self-assertive; if he thinks he is trodden upon he will resist and "scrap" to the end. Engineering firms convinced that steam or some other type is the thing, will go into research to establish themselves. There is greater breadth of view over there. They have vehicles of quite different types that are very successful.

The Airplane Industry

The problems of the airplane industry are troubling France and England very much. They are wondering what to do with the factories and studying the commercial aspects of aviation. If one judged what is to happen from the newspapers, he would think that transportation is to be taken over entirely by airplanes. Yet there is a strong movement to stop any headlong plunge into commercial aviation. They are trying to check rashness. When I left they had prohibited any organization from promoting passenger air service between England and France, because there were no international rules permitting it. If one of the big planes started and some day had an accident with all killed, commercial aviation would be set back. They are looking into the question

Digitized by Google

sanely and are fully alive to the value of aviation. When we left at the end of January airplane factories were still going along, one with orders for 150 big bombing planes and another had orders for 300. They are going to build an aerial navy and plan to dominate the air as they have dominated the sea. For commercial aviation they are laying their plans just as broadly.

They must have landing fields every 10 miles, day and night signals, signals that will serve for use with their radio equipment. They must have meteorological stations and they are working on schools of air navigation, and training their men as sea captains. They are working on mail traffic and insisting on that and express and merchandise carriage, putting passenger travel last. All these fundamentals are to be settled and installations made before there can be a great air transport system.

While the Zeppelin has been a failure in war, it is recognized as a possible tremendous success as a vehicle of commerce. They are not taking transatlantic flight very seriously, but concede that it will be accomplished with the dirigible. They have in London now airships that could make the trip from there to New York City and back without landing. Long flights, like those from New York to Chicago, for instance, are for dirigibles and not airplanes.

Our aviators on the other side used the French Spad plane entirely; all single-seater fighting was done in them. While we heard nothing but praise of the Liberty engine, our planes were not so successful. We heard criticisms of the DH-4 plane. These came from our own organizations, our pilots and observers. Our planes did not have parachutes and we lost many aviators for that reason when the machines took fire. The German Fokker machine had parachutes, with a strap around the pilot. We knew about parachutes, of course. We demonstrated them in 1917. They wondered in France why we did not have them.

Our aviators certainly deserve great credit. They went against the Boche handicapped. We did not have a fighting plane at the front with a protected gasoline tank, that is a tank with laminated rubber bound in with wire gauze, to prevent the tank from taking fire and leaking when struck by a bullet. Requests came from the other side for these almost a year ago, urging that they be sent, but our aviators went into the air with the tank

Digitized by Google

vulnerable to the incendiary bullet, and this meant death if the tank was punctured.

Solid Tire Mileage

I was surprised to learn that on London streets a mileage of 60,000 is secured from the front tires; the average is over 40,000. On the rear tires the average is 30,000 miles on streets not very good. These are solid tires. If it is possible to get that mileage on London streets, what an argument for us to get good roads and highways between our cities and work up to a mileage like that. There is a great deal of stopping and starting in the operation of the London buses; often twenty stops to the mile.

Motorcycles

The feeling over there is that there will be a great motorcycle demand. Great Britain has 140,000 coming back from the war. In France it is said to be respectable now to do three things not thought of before the war; to wear a wrist watch, smoke cigarettes and ride in the side car of a motorcycle. Motorcycles are to be seen in Paris and London, and there is no reason why we should not use them as part of a taxicab system in America.

There was a great demand over there for a small, light car like the Ford, a car cheap to operate. On the boat with us on our return trip were some people coming over to learn whether they could buy parts in America with which to build a light car to carry two, not three, people.

THE DISCUSSION

QUESTION: What about the steel foundries over there? Is any high-grade steel casting work done?

MR. BEECROFT: Yes, a good deal. Fiat has a big steel foundry with four huge 10-ton cupolas, and Lancia has another. Renault has one and there are several in England. A great development has taken place in that line. I spent a day at the National Physical Laboratory, which corresponds to our Bureau of Standards, and was struck with the enormously practical work they were doing there. That organization was responsible for the copper-aluminum alloys. They were rolling aluminum 0.003 in. thick. In another place they were treating steels on a commercial basis. There is a practical aspect: they have put through and approved twenty steel standards for the automobile trade. They called the steel makers and the

Digitized by Google

automobile manufacturers together and for a period of 11 months developed steel. Last October the steel mills started on the production of these twenty new grades of automobile steel.

QUESTION: What fuel is used in the steam vehicles in London?

MR. BEECROFT: Mostly fine soft coal. In December coke was used and giving much greater mileage. In France they are using a fine-dust coal.

QUESTION: How many men are used on them?

MR. BEECROFT: Two, a driver and a workman. The vehicles are simple to operate. It takes about 1 hr. to get well-fired-up in the morning.

QUESTION: What is the present life of the airplane engine?

MR. BEECROFT: I do not know. One gets various opinions. On the front they are generally overhauled every 35 to 75 hr. Renault was guaranteeing engines for 50 hr. on the front before overhaul.

Digitized by Google

METROPOLITAN SECTION PAPERS

ADAPTING THE FUEL TO THE ENGINE[1]

By E W Dean[2] and J P Smootz[3]

BUREAU of Mines refinery statistics for the calendar year 1918 show a production of different types of petroleum fuel products represented by the following approximate figures:

Product	Gal.
Gasoline	3,600,000,000
Kerosene	1,800,000,000
Fuel oil	6,600,000,000

Added to this are 3,100,000,000 gal. of crude oil, used as fuel without refining. The statistics do not distinguish the different classes of fuel oils, and the following provisional estimate has been made:

Product	Gal.
Gas oil or distillate fuel oil	800,000,000
Light residuum fuel oil	2,000,000,000
Heavy residuum fuel oil	6,900,000,000

Processing or refining costs for the different oils are difficult to estimate and of little significance in determining the selling price, which is controlled by the law of supply and demand. All types in the last list can be used in so-called heavy-oil engines, but the gas oil and light residuum are most desirable in the order given. They are less plentiful than the heavy-residuum type which generally cannot be used without special equipment for preheating. The proportionate yield of gas oil can be increased if a sufficient demand is developed. It is not yet settled whether on general principles it is desirable to design and construct engines that will utilize the heavy-residuum products or it is desirable to pay the additional price that will induce refiners to produce larger quantities of gas oil.

The Bureau of Mines, in the course of its work to promote efficiency in the utilization of mineral resources, has devoted much attention to the problem of fuel for internal-combustion engines. Up to date gasoline has been the principal product of interest, but the present

[1]Published by permission of the Director of the Bureau of Mines.
[2]Petroleum chemist, Bureau of Mines Experiment Station, Pittsburgh, Pa.
[3]Petroleum technology section, Bureau of Mines.

Digitized by Google

discussion concerns those fuels that are used in so-called heavy oil engines. An endeavor has been made to present some simple fundamental information regarding a group of petroleum products that are usually regarded as nothing more interesting than a source of heat.

Types of Fuel Products Derived from Petroleum

The fundamental operation in the refining of petroleum is distillation or fractionation. Crude oil is boiled in suitable stills and the vapors are condensed. Those products which are "lightest," that is, have the lowest boiling points, are removed first. The heavier, or higher boiling products, distill later or may be separated as a residue left in the still. The distillation process is sometimes complicated by the phenomenon of cracking which occurs in certain types of refinery procedure. Cracking is actually nothing more nor less than destructive distillation, or decomposition by heat, and the production of kerosene by this means has been standard refinery practice for many years. The production of gasoline by cracking is more or less an innovation and involves the use of pressure, whereas the older types of cracking or coking stills operate at atmospheric pressure.

The fuel products separated from crude petroleum may be grouped under the following classes:

Gasoline
Kerosene
Gas oil or fuel oil distillate
Light residuum fuel oil
Heavy residuum fuel oil

Properties and Method of Production

An adequate discussion of the properties and methods involved in the production of these different types of petroleum fractions would be beyond the scope of the present paper, but a brief description may serve to indicate differences that are of economic importance.

Gasoline is a product that is so familiar and so frequently discussed that it needs little description in the present connection. Its production ordinarily involves distillation, chemical treatment and redistillation. Its essential properties are volatility and a degree of purity that is indicated by freedom from colored and malodorous impurities.

Digitized by Google

The production of kerosene requires also a primary distillation, chemical treatment and redistillation. The essential properties of kerosene are safety and ability to burn satisfactorily from a wick.

The petroleum fractions classed as gas oil or fuel oil distillate vary over a wide range of physical and chemical properties. Their production generally involves a single distillation, and they are not subjected to chemical treatment. Their common characteristic is practical freedom from asphaltic or pitchy constituents that form coke when the oil is heated strongly enough to cause complete vaporization. In addition to its numerous industrial uses, gas oil is at present the preferred material for transformation into gasoline by the pressure-distillation cracking processes.

Residuum fuel oils vary over an even wider range of physical and chemical properties than do distillate fuel oils. Their essential characteristic is a content of pitchy, asphaltic material, which decomposes with the formation of coke when the oil is heated strongly enough to bring about complete vaporization. There is no clear-cut line of demarcation between products classed in the present discussion as "light" and "heavy," but a distinction has been made on the basis of viscosity or ease of flow. Oils that require preheating before they can be handled in ordinary equipment are classed as "heavy"; those that flow satisfactorily without this treatment are classed as "light." Residuum oils are more likely to contain such impurities as water and sediment than are distillates, and this tendency is more marked with the heavier than with the lighter products. Most of the high sulphur oils, such as those from Mexico, are of the heavy type, though not all heavy residuum oils contain excessive percentages of sulphur.

Quantities of Different Oils Available

The Bureau of Mines refinery statistics for the calendar year 1918 show a production of the different types of fuel products represented by the following approximate figures:

Product	Gal.
Gasoline	3,600,000,000
Kerosene	1,800,000,000
Fuel oil	6,600,000,000

The total amount of unrefined crude oil consumed in the United States in 1918 was 3,100,000,000 gal.

Digitized by Google

The actual statistics do not distinguish between the sub-classes grouped under fuel oils, but these have been subjected to the following provisional estimate:

	Gal.
Gas oil or distillate fuel oil	800,000,000
Light residuum	2,000,000,000
Heavy residuum	6,900,000,000

The high figure for heavy residuum was obtained by considering all unrefined crude oil consumed in the country as being in this class. The present distribution among the three sub-classes, whether or not it is accurately represented by the figures just given, is actually determined in the main by conditions of profitable marketing. The methods and equipment now used in refineries would permit considerable increases in the production of certain types of oil, if demands warranted the necessary changes. The yield of gas oil or fuel oil distillate, in particular, could be notably increased if its market value were sufficient to render profitable its separation from the residuum oils. Light residuum oil can be converted into distillate and heavy residuum, and the latter can be distilled and cracked into oil and coke.

The Bureau of Mines is not in possession of figures indicating with any degree of exactness the actual cost of producing the types of products listed and can discuss this subject only in general terms. Manufacturing or processing costs are approximately the same for gasoline and kerosene, notably smaller for gas or fuel oil distillate and still less for residuum oils.

In actual fact, these processing costs do not seem to be of more than minor practical significance, as the selling price of petroleum products is now, and probably always will be, determined chiefly by the ratio between supply and demand. For this reason, it is more desirable to estimate the probable future cheapness or costliness of oil fuels on the basis of figures pertaining to production and consumption, rather than on actual costs of treatment and handling in the refinery. This fact is brought out particularly well by the present ratio of more than two to one between the market prices of gasoline and kerosene which are products costing approximately the same to refine.

Digitized by Google

Author's Conclusions

The present paper has indicated that there are available for use in heavy oil engines several types of petroleum products that vary considerably in physical and chemical properties. It does not appear, however, that the desirability of any particular type of product is so definitely established as to be independent of the conditions under which it is to be used. The heavy residuum oils are cheapest and most abundant, but probably the most difficult to utilize. Light residuum oils are less abundant and though more satisfactory to use than the heavy are uneconomical for the refineries to turn out, as they contain products of greater value, such as distillate fuel oils and lubricants, that can be separated by simple refinery methods when there is sufficient demand for such fractions.

Distillate fuel oils are inherently more costly to produce than the residuum types but are potentially plentiful and are satisfactory to use. One circumstance that modifies their desirability as fuel for heavy engines is the fact that they are likely to be required in increasing quantities for transformation into gasoline by the cracking processes.

Kerosene is the least abundant and most expensive of the several fuel fractions. Its utilization in internal-combustion engines would be a highly desirable accomplishment for the immediate future but such a practice does not seem to provide an addition of any real importance to the country's resources of petroleum fuel.

THE DISCUSSION

W. P. Deppe:—As shown in the paper, the production of refined oils in the United States for 1918, was roughly divided into engine gasoline, 85,000,000 bbl.; kerosene, 45,000,000 bbl.; and fuel and gas oils, approximately 170,000,000 bbl. Inasmuch as a large part of the kerosene is vitally necessary for people who require lamps and stoves, not much more can be added to the present engine fuels. Hence the problem of fuels possible from mineral oils resolves itself into adding fuel and gas oils cracked to what is now sold for engine fuels.

In 1918 the fluid sold for engine gasoline in America averaged 36 per cent with boiling points above 300 deg. fahr., which thus means that 36 per cent of what is now

Digitized by Google

sold for engine gasoline has boiling points in the kerosene series. The cracked fuel and gas oils of the future added to what is sold for engine gasoline means something in the way of fuels.

The fundamental trouble to-day, in this whole problem of engines and their fuels, is the fact that neither the automotive engineers nor the chemists to whom they look for technical knowledge seem to grasp the simple fact that all engines burn a fluid called gas. That gas must be raised to its ignition point, about 1000 deg. fahr., and consists of very definite proportions of air and the vapors of oils or other hydrocarbons.

The range of complete combustion of say 73 deg. Baumé gasoline in air, is between 1.5 and 2.5 per cent, yet all motor cars, with wet mixture carburetion methods, operate on ratios below 15 to 1 of air to oil vapors. All the lubrication troubles, all the knocks of which engineers and the public complain and which Mr. Kettering and Mr. Hunt so clearly bring out, disappear when the oils in air are transformed into true gases before the moment of ignition. Sending oils in the form of a liquid suspended in air into the cylinders of an engine designed primarily for gas fuels, is much the same as putting flour, eggs, yeast, sugar and flavoring extract into a cake pan and baking that unmixed mass of otherwise very good raw materials.

Almost 200,000,000 hp. of gas engines in trucks, tractors and passenger cars will be in use by the end of 1919. There are less than 50,000,000 hp. of steam engines in use, and less than 3,000,000 hp. of Diesel engines. Therefore the greatest problem before the S. A. E. and the oil refiners is the provision of fuels for the 200,000,000 hp. rather than the limited amount of heavy fuels for the Diesel type of engine, which when mechanically perfected over its present well-developed state has no cause for worry about fuels.

Engineers and chemists attempting to deal with this problem must recognize the fundamental laws of physics and chemistry relating to liquids, the characteristics of the hydrocarbons in oils, their relation to the air gases, their melting and boiling points, critical temperatures, etc. Treating this problem altogether on mechanical lines, and ignoring the physical and chemical phases is, in the final analysis, the reason no progress has been made toward deciding a rather simple question in business economics. The problem in a nutshell is that en-

Digitized by Google

gines are built to use gas fluids as fuels. We are injecting liquid oils suspended in air into the cylinders. This causes all the technical troubles of the oil refiner to develop when one attempts to produce gas in the narrow ratios of combustible limits of oil and air, under exceedingly high pressures in the presence of flame, and within time limits far too short for complete combustion in any type of existing engine. We may keep our eyes shut to these simple facts, but within the next year or two this question must be solved commercially or the gas-engine industry will have reached its limit temporarily, until men in high places and supposed to know the technique of their industry wake up to their now unfortunate position on this worldwide economic problem.

HOT SURFACE OIL ENGINES FOR INDUSTRIAL PURPOSES

By A H Goldingham[1]

THE oil engines described are for stationary or land installations and are of the "hot-surface" design with combustion at constant volume. Progress in the design is referred to and the thermal efficiency of modern designs is compared with that found in engines twenty-five years ago. Three important features are reviewed, namely: (*a*) Reliability, (*b*) first cost and (*c*) economy.

Improvements in the design of spraying devices, and other details of construction which have brought about greater reliability, are referred to. Dimensions of large two and four-cycle oil engines are given, and the first costs of each type are contrasted. The greater economy of the modern oil engine as compared with the earlier type is explained. Indicator cards, test data, speed, weights and other details of interest are enumerated concerning the De La Vergne SI type of oil engine, this being an example of the results obtained in a modern hot-surface-type oil engine.

The oil engines referred to in the following remarks are of the horizontal or vertical design arranged for a direct connection or by belting to electrical or pumping and other machinery. They are slow or medium in speed, operate on the four-cycle or two-cycle plan and are gen-

[1]De La Vergne Machine Co., New York City.

Digitized by Google

erally known as the hot surface type, although sometimes and erroneously they are termed semi-Diesel engines. This designation is derived from the "hot surface" constructed according to various designs including an electrical coil from which the heat that causes the ignition of the mixture of fuel and air in the combustion space is first obtained. This title is given in contradistinction to that of the "Diesel" type in which ignition is caused by the heat of compression alone, and where combustion is at constant pressure, while in the former type combustion occurs at constant volume.

About 25 years ago one of the leading British oil engine manufacturers offered a prize to any employe who could operate an oil engine continuously for 10 hr. at full load. Today many "hot surface" oil engines operate at full load for 6 months without stopping. A few years ago the lighter fuels only could be used; today these engines are guaranteed to operate successfully and continuously on any fuel or crude oil produced in the United States or Mexico, which includes crude oils of 11 deg. Baumé or heavier, while the guarantee of 1 lb. of fuel per b.hp.-hr. or a thermal efficiency of 14 per cent in 1900 is today replaced by a guarantee of 0.45 lb. per b.hp.-hr. and even 0.39 and 0.40 lb. are reached successfully. These facts show most emphatically the progress which has been made in the modern "hot surface" type oil engine during the last 10 to 20 years. In a brief survey of this part of the subject let us look at three important features which call for the time and thought of the manufacturers, are of supreme importance to purchasers and are of significance to all who are interested in the subject.

(1) Reliability
(2) First cost
(3) Economy

I have named these features in this order because I think and will try to show that their relative importance to each other is in that sequence.

Reliability

I have placed the feature of reliability of operation first and regard it of prime importance because no matter how high the economy or how low in the first cost, if an oil engine is not as absolutely reliable in operation as say a high-grade steam plant, it is useless and proves to be a

Digitized by Google

poor investment. Years ago the oil engine had an unenviable reputation. The modern oil engine of leading manufacturers is quiet in operation, is frequently maintained for several months continuously at full load without stoppage and the exhaust is almost odorless and nearly invisible. This great improvement is largely due to more thorough atomization of the spray entering the combustion space, improved construction of the vaporizing chamber, force-feed lubrication of all moving parts, automatic air-starting inlet valves and improvements in the method of supplying heat to the vaporizer.

The modern sprayer is designed either to inject the fuel by high-pressure air as in most Diesel engines, or it is injected through a carefully designed and minutely constructed mechanical sprayer of the "solid-injection" type and proportioned so that a dry spray results, entering at such speed and volume that all particles or globules of hydrocarbon are thoroughly diffused, reach the distant points of the combustion area, have the maximum amount of their surface exposed to and are intimately combined with the oxygen of the air in the vaporizer or combustion space. In addition to the improvements in the sprayer the correct construction of the fuel supply pump, in its operating cam or eccentric and governor have assisted in obtaining this effect.

The method of solid injection now used by many English builders utilizes an accumulator consisting of an oval steel tube into which the fuel is first delivered at a pressure of 4000 to 5000 lb. When the spray valve is mechanically opened the atomized spray is instantaneously injected at its maximum speed resulting from this great pressure. The slower speed at the beginning and end of the pump stroke ordinarily found where a cam motion is employed, is thus eliminated. This method has been applied to both Diesel and hot surface engines with great success.

The improved construction of the vaporizing chamber ensures proper and reliable operation at lighter loads, while the employment of force-feed lubrication to all moving parts allows both a correctly measured and a continuous supply of lubricating oil.

The use of automatic air-starting inlet valves makes certain the admission of compressed air to the cylinder at the correct period of the cycle, and proper closing of the air supply.

Digitized by Google

Improvements in the vaporizer heating lamp by the use of higher pressures, result in obtaining greater temperature and quicker starting. In the lampless types the modern use of an electric coil for furnishing the heat necessary at starting enables this type to be started as quickly as the Diesel engine, or where the lamp is used for heating purposes, starting can be effected in 3 to 5 min.

First Cost

The hot surface type is now built in sizes from about 10 to 400 hp. for land purposes. The gasoline engine is preferred below this limit, and above 400 hp. either the Diesel type has advantages, or the steam turbine can successfully compete where conditions of fuel, water and attention available are normal. The largest size cylinder without piston cooling is 21 in. in diameter with a 34½-in. stroke operating at 908-ft. piston speed, the engine weighing 425 lb. per b.hp. The first cost in 1913 was $55 per b.hp. Today it is about $120 for the four-cycle slow-speed, horizontal design. With the two-cycle medium-speed type having a piston speed of 740 ft., a cylinder diameter of 14 in. and a stroke of 18½ in., the price in 1913 was $55 and now is $90 per hp.

The first cost of an oil engine is a very important feature because in most cases the item of interest and depreciation, which is generally figured at 10 per cent and divided equally between interest and depreciation, is the greatest charge in the balance sheet showing the cost of operation. For instance, the fuel cost of a 100-hp. oil engine consuming 0.45 lb. per b.hp.-hr. is $1,000, based upon a run of 3000 hr. per yr. and a cost of 6c. per gal., while the interest and depreciation charge on the basis outlined would be $1,200. With the oil engine lower in first cost but where the fuel economy might possibly not be so high and maximum reliability of operation was still retained, the more general use of the oil engine in this country would follow.

At present 42 per cent of oil engines for land installation are used for pumping oil or water, 19 per cent for electric lighting and 39 per cent for general power purposes.

Economy

The thermal efficiency of the modern hot surface type oil engine is 30 per cent, and comparing this with 14 per cent, as previously mentioned, shows a great advance.

Digitized by Google

This improvement is due to the higher compression pressures now employed and to more efficient spraying or pulverizing of the fuel. In the earlier oil engines the injection of the fuel proceeded during the air inlet period or the first part of the compression stroke. The cylinder or combustion space was thus filled with an explosive mixture during the compression stroke or period, and accordingly only that pressure of compression was allowable which would make the temperature of the mixture being compressed rise to ignition conditions.

With the lapsing of the Diesel patents in about 1904 the feature of that engine, namely, the injection of the fuel at or near the end of the compression stroke was adopted by most hot surface engine builders. This system allows a higher compression pressure as the air only is compressed and the danger of preignition present in the earlier engines is eliminated. The processes of fuel injection and ignition in the modern engine are practically simultaneous.

One of the latest and at present most interesting designs of hot surface oil engine is the De La Vergne S I type designed with both the horizontal and vertical multicylinder construction. This engine starts instantaneously when cold without a heating lamp, the initial heat being supplied from an electric coil.

The particulars of a test on a 100-hp. four-cycle single-cylinder engine of this type are given on page 695 and a set of indicator cards taken under various conditions is also reproduced on the same page.

The engine tested had a single cylinder of 19-in. diameter, a 24-in. stroke and operated at 200 r.p.m. It used as fuel an oil having a specific gravity of 34 deg. Baumé and a flash-point of 144 deg. fahr. The heating value of the oil was 19,350 B.t.u. The amount of cooling water consumed was 3 gal. per b.hp.-hr. and the inlet and outlet temperatures were 65 and 130 deg. fahr., respectively. A compression pressure of 225 lb. and a maximum ignition pressure of 450 lb. were used and the starting air pressure was 100 lb. The fuel consumption ranged from 0.41 lb. per b.hp.-hr. to 0.72 lb. at one-quarter load. The exhaust was invisible and had a temperature of 650 deg. fahr.

THE DISCUSSION

H. C. VERHEY:—My first experience with the Diesel engine dates back about 12 yr., at which time I had an

Digitized by Google

opportunity to see some drawings for this type of engine in Augsburg, Germany. We soon after started work on an experimental engine which we bought. We experimented with the running, and all that sort of thing, which was very easy. Then we started to build our own engines, sending engineers and shopmen over to see how they did things on the other side. When our first two-cylinder, 100-hp. engine had been running for about 1 hr. there was an awful noise, then a great explosion which made us feel that the whole Diesel was going up in the air; then the compressor stuck and a few more things happened.

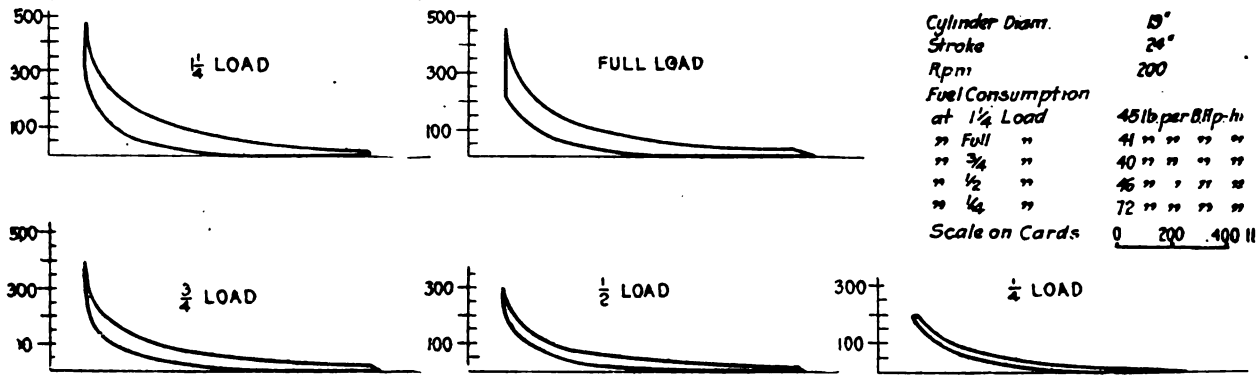
We knew that we had secured all the information we needed from the manufacturers abroad. The trouble was that we did not have the slightest idea how to run the engine in the shop, giving the proper clearances and introducing the oil in the correct way, and the proper attendance was lacking because we had had no experience.

Diesel engineers and the statisticians also are further advanced today because foreigners, particularly the Danes and Swedes, have been coming regularly to this country with their big ships, and the Dutch, on a lesser scale with smaller ships.

Formerly, when people went over to inspect these new engines very little attention was paid to the reciprocating engine, particularly by the men interested in the manufacture of steam installations. Today there is a different tendency. At a meeting like this, we automobile engineers become familiar with the troubles that are common to these heavy-oil engines. This is the first step toward real success, which I feel cannot be very far away.

I was fortunate enough to be sent out by one of the few really successful American firms, those that have gone through various serious hardships and emerged successfully. In 1914 I went to Switzerland with the sanction of the Secretary of the Navy, since I was not a full-fledged citizen at that time, to study submarine engine designs. I got back with many drawings after this country was in the war. We copied the engine, but the ship was not in position to take it in that form, and we had to do everything over. We did right here in this country some work which resulted in an engine that does not crack pistons or heads, which shows that where there is the will to do certain things, those things can be done.

Digitized by Google



SERIES OF INDICATOR CARDS OBTAINED IN A TEST OF A NEW FORM OF HOT SURFACE OIL ENGINE

Digitized by Google

In fact, going to Europe for talent and workmanship for Diesel engines is absurd. Our material here is superior to theirs. We have had less trouble with pistons from the very beginning, when our people did not know how to make them or how they should apply clearances, and particularly how to take care of lubrication and such little things, than they had in the early development of the Diesel engine in the old country. Naturally, we cannot be too proud of that, because where the other fellow ended, we started, but we should appreciate at its full value the fact that our manufacturing facilities are better than those of Europe; that we have acquired all the information Europe has; that companies over here are today making things, particularly in the line of castings, that cannot be surpassed by any firm in Europe. I have seen these things, and I know this to be true. Certain castings which were tremendously difficult to make came out splendidly. That sort of work has been most successful. All that is needed to give us confidence in our ability to tackle this thing is the cooperation of engineers. Such an engine can be made. A big Diesel engine is no hard proposition for the well-established manufacturers of this country. I have been able, due to my position, to watch what they are doing, and, gentlemen, it is superior to what is done in Europe today.

CARL GEORGE DE LAVAL:—I have noted with some apprehension the great effort made by various Scandinavian companies to establish factories in this country, and by advertising and sales propaganda to lead the world in internal-combustion engine design. We should not sit idly by and allow this situation to be developed by Europeans, who import engines and are now establishing factories here, such as those on the Pacific coast, to obtain the trade that rightfully belongs to us. There is no mystery in building these engines. The achievement of the Europeans is not by the extraordinary merit of any particular type or design, and if we only stop to consider the situation, we will engage in it ourselves. The here. Our need and output are much greater, and we are looking for work for our returned soldiers, here is a field we can enter and thereby employ a great number of men.

We have learned the lesson in these last years that petroleum will bring order out of the present situation by its new mechanical advantages. We have not paid enough attention to oil, as coal has been cheaper; we

Digitized by Google

have not fully considered its advantage over coal in reducing final costs. For marine purposes, because of its advantage in the reduction of bunker space, increased mileage, elimination of fire risk, increased ship operation and reduction in operating expenses, we shall be forced to enter this field in competition with the Europeans. From now on we are in a new era for both marine and industrial power, heating and the multiplication of benefits that will result. Under new conditions we shall work out our problems more successfully.

For ordinary use the internal-combustion engine bids fair to be the most successful in its proper field, operated by ordinary men, and such engines should be made reliable, easy to run and not too expensive. Finish for external surfaces is of secondary importance. Even Chinamen in Canton are now making copies of these simple surface-combustion engines, competing successfully with foreign makes. They selected the hot-bulb engine as being the simplest for use on their fishing junks. When a Chinaman can see good reasons for adopting such petroleum engines, we certainly should be ready to introduce them more extensively in our harbor, river and canal work, in industrial establishments and many other places. To succeed they must be cheap in first cost and so simple to operate that a man with no mechanical knowledge can run them with a little instruction. Engines must withstand abuse and must not be dependent on magnetos or batteries for ignition.

Mention has been made of various failures in our merchant marine with oil engines, because of unsuitable and untrained labor. This is a situation that must be met by the designer and builder. It differs from the European problem in that they always have men who are well trained along this particular line. It is different here. Our need and output are much greater, and we must build engines that can be run by anyone, regardless of training.

In the development of this industry and its great importance to production in our country, it is absolutely necessary that the engines be made here and not 3000 miles away, and, incidentally, we must endeavor to corral our own fair share of the profits.

There are no fundamental patents in force on either Diesel or hot-bulb designs, and the foreign patents pertain to minor details only, which can be worked out in various ways. We can benefit by the purchase of Euro-

Digitized by Google

pean drawings and follow some of their methods, but these will eventually be given up as unsuited to American manufacture and use and replaced by designs adapted to our conditions and requirements.

One of the industries in need of immediate improvement along modern lines is the great Atlantic and Pacific fishing fleets. Both fleets cover thousands of miles of coast line of vast seas and gather immense harvests of fish for food consumption. These fleets consist of thousands upon thousands of boats, trawlers and schooners, the greatest aggregation of small-engine vessels in the world, operated for the most part by gasoline, whereas they should be operated by heavy oils.

We are now approaching another field of development, due to the expansion of our waterway or canal and river system. Recently the Government purchased a large fleet of barges for the New York State Barge Canal; also a large fleet for the Mississippi River. These latter packets will ply the Mississippi and be equipped with a complete power handling outfit for their cargoes. Unfortunately the Government prohibits the use of hot-bulb surface ignition oil engines, because of the conveyances themselves and the large amount of cotton handled by them, yet misfiring, or the exhaust from the muffler of a gasoline engine, is undoubtedly more to be feared than any part of an oil engine. Hot-bulbs can be sufficiently water-jacketed and protected by hoods to eliminate the danger of fire, and the exhaust will be free from all menace.

Such extensive transportation routes as rivers and canals offer should be operated by engines using low-grade fuels. As I have said, this is one of our basic industries, which lends itself to the application of internal surface-combustion engines, because of the relatively low horsepower required. It is an industry which requires outfitting on a big scale and both manufacturers and dealers must be prepared to cater promptly to all needs and demands. It can only be handled by our own people. The members of the various engineering associations should take energetic action to start the proper development. There is no parallel for it in the world. We are only beginning to appreciate the immensity of the market throughout the country, and when the facts are better known, home producers of hot-bulb engines will establish shops in all parts of the country to secure their share of the business. The growth and develop-

Digitized by Google

ment will undoubtedly be rapid and it is absolutely necessary that many of us take hold and do our share.

I have watched with interest the attempts to convert the gasoline engine to the use of kerosene. To my mind the contrivances described as additions to the engine will only complicate the problem. Without going into technical details it may be well to state that working with conventional devices may prove partially successful for carbureting kerosene, but existing differences in boiling point, temperature, chemical constituents, heat, etc., inhibit any satisfactory solution. Commercial success does not lie that way. If we are to burn kerosene and cheaper grades of oils as fuel in engines for launches, tractors, motor boats and farm engines, a simpler design must be brought out, free from the valves, traps and contrivances now used on the ordinary gasoline engine. We must cut loose from the conventions and traditions, and strike out on new lines. This is the class of commercial work needed today on oil engines.

NATHANIEL B. WALES:—What we as engineers most desire to produce is an engine which will operate efficiently on the entire range of fuels, even including alcohol, to meet the paramount fuel problem adequately.

Let me suggest then, a most rational and logical means. We all feel assured that the high-compression type Diesel engine will operate on non-volatile and base fuels; we also know with equal certainty that we can operate the present type of automotive engine at high speeds, combined with a minimum engine weight and low initial cost. Let us, therefore, endeavor to combine the Diesel and Otto cycles within a single engine structure, retaining the best points and characteristics of each, building, as it were, "an engine within an engine," or more precisely, a minor Diesel engine, the sole function of which with its small 2-in. bore cylinders is to "prepare" the fuels in gaseous form for rapid combustion in the major cylinders. The two cylinders might be cast integrally, looking like a conventional L-type engine, the Diesel piston performing the entire valve function for the major cylinder. This preparation of the fuel for rapid ignition in the major cylinders would be brought about by introducing a wet cold mixture of air and fuel into the Diesel cylinders before compression, a mixture in which the air content is insufficient to support combustion of more than a fraction of the hydrocarbon mass so introduced, then compressing it to a point where the

Digitized by Google

more volatile portions of the fuel preignite. This would take place just before the top dead center, or at a crank angle comparable with that at which the spark now occurs. This partial burning of the mixture would generate intense heat which, plus the heat of final compression, would throw the entire fuel mass above its critical ignition point, but from the lack of oxygen, due to the limited air volume, this fuel would be unable to complete its oxidation.

When the piston reached its topmost position it would register by a slot with the clearance volume of the major cylinder, and the gas now above its critical ignition point would be released to the major cylinder wherein it would complete its combustion, burning in the presence of an excess of oxygen.

In this manner the main cylinders would be relieved of high compression, and weights and costs would be brought down to compare with the standard automotive engine. By using an adjustable cylinder-head in the small 2-in. Diesel cylinder which can be instantly changed by a lever comparable to the spark-lever on the steering-wheel, the compression ratio can be varied for the fuel used so as to determine the point of preignition in the cylinder and attune it to any fuel. By the ability to change the compression ratio instantly, the wear and changing heat levels of the engine can be compensated for.

Digitized by Google

PRESENT POSITION OF THE DIESEL ENGINE AS APPLIED TO MARINE SERVICE

By Thomas Orchard Lisle[1]

THE ill treatment of a promising type of cargo carrier, the American large wooden motor-auxiliary, has been most unfortunate. This class of vessel was unsuccessful in many instances for the following reasons:

(1) Most of the hulls were constructed of green timber by inexperienced builders, and the hogging and warping of the hulls assisted in causing unreliability in their machinery

(2) They had insufficient canvas to make profitable speed under sail alone

(3) Their auxiliary power was insufficient to drive them at a profitable speed without the sails and a favorable breeze and sometimes even with all these

(4) These craft, built as auxiliaries, were operated as full-powered ships, which resulted in a continual forcing of the engines to their limit of power, and tended to unreliability

(5) Inexperienced engineers were placed in charge instead of men sent to the engine-builders' works for several months while the vessels and engines were under construction

Many of these vessels have a load displacement of over 5000 tons, yet in no case was over 700 hp. installed. Such vessels, properly built, suitably filled with good oil engines and well operated, have demonstrated conclusively that the motor auxiliary can more than hold its own against the coal-burning or oil-fired full-powered steel steamships.

A short statement is given of the cargo ships built during the war in England, Italy and the United States. The general policy of the Shipping Board toward cargo carriers, the placing of orders in foreign countries for engines to be used in these ships and the wholesale cancellation of these orders later on, are criticized adversely. In connection with the solid-injection Diesel engines, the British firm of Doxford & Sons is building

[1]Editor, *Motorship*, New York City.

Digitized by Google

some standardized 11½-knot single-screw motorships, each fitted with a four-cylinder, two-cycle type Diesel engine of 3000 i.hp. at 77 r.p.m.

This engine, which, strictly speaking, is not a true Diesel, has a cylinder output of 750 i.hp., or approximately 500 b.hp. It will burn oils of 0.96 specific gravity and containing 30 to 35 per cent of asphaltic matter. Cammell-Laird & Co. of Birkenhead, England, are also developing a new opposed-piston type of Diesel engine which offers great possibilities. Sulzer Freres of Winterthur have placed in service two six-cylinder, two-cycle type Diesel engines of 4000 to 4500 b.hp. each. These are stationary engines, one in France and the other at Harlan & Wolff's drydock. There is no reason why such engines cannot now be built for marine work. In fact, a successful six or eight-cylinder Diesel engine of 5000 b.hp. (6500 i.hp.) could probably be built to-day. An order for a triple-screw liner of about 20,000 i.hp. or a twin-screw freighter of 13,000 i.hp. could be placed with confidence by the Shipping Board or a shipowner with sufficient courage and foresight. The freighter would be a 16-knot ship of 20,000 tons capacity. With drawings and assistance from abroad the engines could be built in the United States. As this vessel would have a fuel consumption of only 43 tons of oil-fuel per 24 hr. at full speed and would not need more than twenty men in her engine room, it would revolutionize long-distance cargo carrying. None of the motorships now contemplated by the Shipping Board will show any advance over foreign motorships already in service. If the fleet of 9800-ton vessels is built, we shall still be behind European engineers in development and progress.

Four years of war have been a great impediment to extensive adoption of the merchant-type of marine Diesel heavy-oil engine. The cry was ships, ships, and more ships, for the thousands of tons of merchandise and munitions waiting for months on the docks of the world's ports. The entire absence of customary trade competition and the prevailing high freight rates made it unnecessary to effect economies in operation; and, as the ships of all nations have been more or less under the control of the various governments, only the more progressive shipowners who had eyes on the future, evinced interest in motorship construction. In Great Britain the demand for naval vessels, of course, retarded merchant Diesel engine development, but some oil-engined monitors with 15-in. guns were placed in service; also some large and small merchant motorships.

Digitized by Google

The American Wooden Ship

Again, many shipbuilders of neutral countries made slow work of delivering such motorships as were on order with them because of the great difficulty in securing materials. Nevertheless, a considerable number of ocean-going motorships were laid down or launched in Europe. In our own country a new type of merchant ship was developed during the war period, namely, the large wooden motor auxiliary. Unfortunately, this type of vessel was unsuccessful in many instances, due principally to the following reasons:

(1) Most of the hulls were constructed of green timber by inexperienced builders, and the hogging and warping of the hulls assisted in causing unreliability in their machinery

(2) They had insufficient canvas to make profitable speed under sail alone

(3) Their auxiliary power was insufficient to drive them at a profitable speed without the sails and a favorable breeze and sometimes even with all these

(4) These craft, built as auxiliaries, were operated as full-powered ships, which resulted in a continual forcing of the engines to their limit of power, and tended to unreliability

(5) Inexperienced engineers were placed in charge instead of men sent to the engine-builders' works for several months while the vessels and engines were under construction

It should be borne in mind that many of these vessels have a load displacement of over 5000 tons, yet in no case was over 700 hp. installed. Less than 150 hp. per 1000 tons is not of much use as a propelling means. Oil engines of this power should have been used only when entering harbors, or as an aid to the sails during calms or adverse winds, but they have been used as a main propulsion medium for 20 to 30 days at a stretch, as on voyages from the Pacific coast to Australia.

This ill treatment of a promising type of cargo carrier has been most unfortunate, since instances of such vessels properly built, properly fitted with good oil engines and properly operated, conclusively demonstrate that the motor auxiliary can more than hold its own against the coal-burning or oil-fired, full-powered steel steamships, particularly on services favored with trade winds.

Digitized by Google

However, I would recommend steel-built hulls for this class of freighter. If the auxiliary power is to be used rather constantly at sea, I would advise the following powers:

Loaded Displacement, tons	Power, b.hp.	Fuel Consumption for 24-hr. Running, bbl.	Average Loaded Speed Without Sails, knots
2,000	500	14 to 16	7½
3,000	700	21 to 23	8
4,000	900	24 to 28	8¼
5,000	1,100	32 to 36	8½

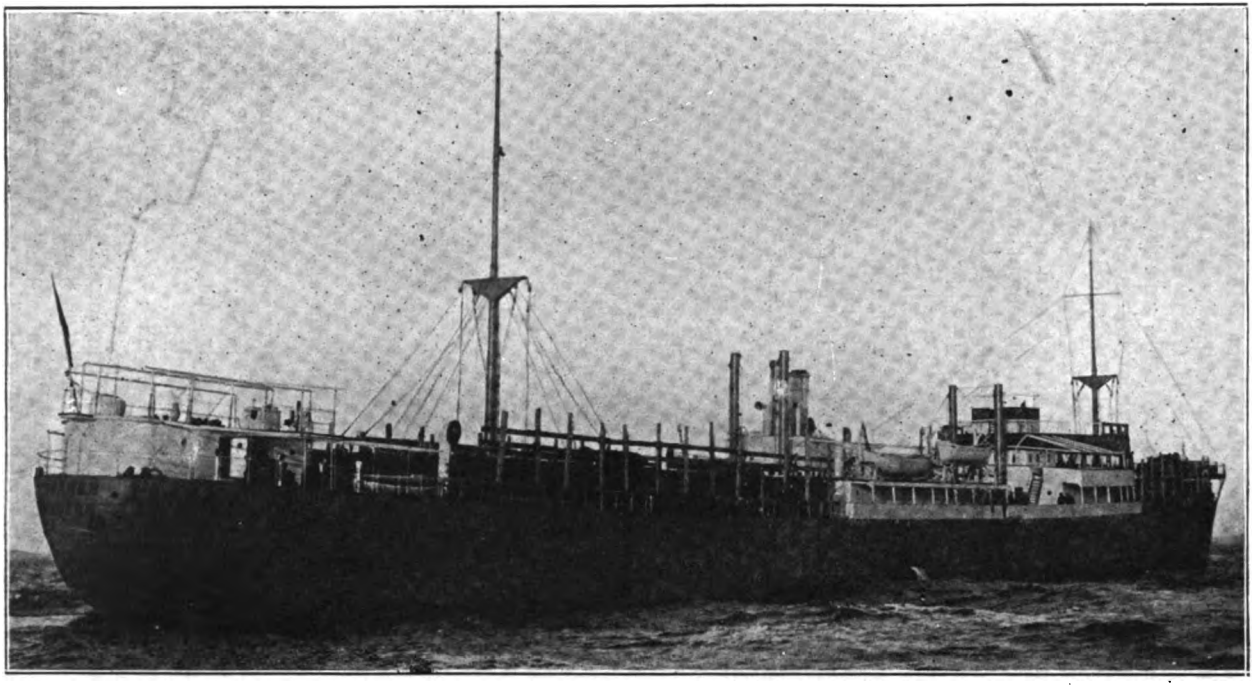
During the war a number of full-powered wood and steel motorships of 1000 to 4000 tons were built in this country and fitted with Diesel engines of domestic design or construction. Generally speaking, these ships have given excellent service, although some are by no means ideal in design. Their total power per vessel is up to 1000 b.hp.

As regards large full-powered steel motorships, America lost a splendid opportunity during the war to construct a great fleet of such vessels, as at the present time and in the near future these would be of incalculable value to the nation. This was not done because from the official point of view the war needs were too urgent to justify experimenting with Diesel-engine power. Another experiment was adopted instead, namely, the geared turbine. This has not been the success anticipated, and judging by the actual results obtained from it in service, the building of motorships would have been much better, both for meeting the emergency conditions arising from the war, and for use in after-war trade.

Yet, Italy during the war decided to build Diesel-driven motorships for her emergency merchant fleet, and one yard alone, the Ansaldo-San Giorgio, Ltd. of Spezia, arranged to launch every year not less than eighteen standardized steel motorships of 8000 to 10,000 tons dead-weight capacity.

No country was in greater need of cargo ships than Great Britain, yet at the most critical period of the submarine warfare she laid down and launched the highest-powered and fastest merchant motorship ever built. This was the Glenapp, a transport-freighter of 470-ft. length and 55-ft. 8-in. beam, with a speed of 14 to 15 knots. Her Diesel engines each have eight cylinders, 760-mm.

Digitized by Google



A Typical Transatlantic Diesel Engine Ship

Digitized by Google

(29.921-in.) bore, by 1100-mm. (43.307-in.) stroke, and together develop 6600 to 7000 i.hp. at 110 to 125 r.p.m. on the four-stroke cycle. If Great Britain could experiment during the war, why could America not do so? An answer is not easily forthcoming.

Another large four-cycle Diesel-driven British motorship placed in service during the war was the Santa Margherita, a vessel of 11,000 tons dead-weight capacity, of about 14,000 tons load displacement and of 2500 b.hp. at 130 r.p.m. from two engines, each having eight cylinders, 20.7-in. bore by 33-in. stroke.

The most important feature of these particular engines is that they are of the solid-injection type, and thus dispense with compressed-air injection of fuel. Their builders were Vickers, Ltd. of Barrow, who have had considerable experience with solid injection in connection with high-powered six, eight and twelve-cylinder submarine engines.

A New Solid-Injection Diesel Engine

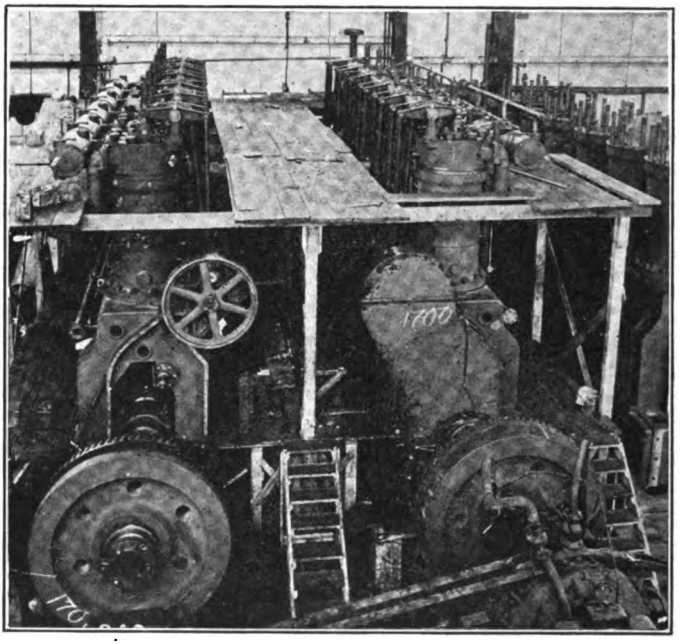
In connection with solid-injection Diesel engines, the British firm of Doxford & Sons is now engaged in the most radical and important marine oil engine development ever attempted, and one which should be watched with great interest by all engineers. It is building some standardized 11½-knot single-screw motorships, each fitted with a four-cylinder, two-cycle type Diesel engine of 3000 i.hp. at 77 r.p.m. The five outstanding features of this engine are:

(1) Solid injection of fuel
(2) Opposed-piston type of engine
(3) Larger output per cylinder than any other Diesel engines under construction for marine work
(4) Lower revolution-speed than any other design of Diesel engine
(5) Low fuel consumption for a two-cycle type engine, this being guaranteed at 0.42 lb. per shaft hp.-hr.

This engine, which strictly speaking is not a true Diesel, has a cylinder output of 750 i.hp., or approximately 500 b.hp. It will burn oils of 0.96 specific gravity and containing 30 to 35 per cent of asphaltic matter. Cammell-Laird & Co. of Birkenhead, England, are also developing a new opposed-piston type of Diesel engine which offers great possibilities. Sulzer Freres of Winterthur, have placed in service two six-cylinder, two-cycle

Digitized by Google

type Diesel engines of 4000 to 4500 b.hp. each. These are stationary engines, one in France and the other at Harland & Wolff's drydock. There is no reason why such engines cannot now be built for marine work. In fact, it is my opinion that a successful six or eight-cylinder Diesel engine of 5000 b.hp. (6500 i.hp.) could be built today. An order for a triple-screw liner of about



A Pair of American 750-Hp. Diesel Engines

20,000 i.hp. or a twin-screw freighter of 13,000 i.hp. could be placed with confidence today by the Shipping Board or a shipowner with sufficient courage and foresight. The freighter would be a 16-knot ship of 20,000 tons capacity. With drawings and assistance from abroad the engines could be built in the United States. As this vessel would have a fuel consumption of only 43 tons of oil-fuel per 24 hr. at full speed and would not need more than twenty men in her engine room, it would revolutionize long-distance cargo carrying. The advan-

Digitized by Google

tages are so tremendous that the United States Shipping Board could well afford to order at least one vessel now. In fact, it is rather surprising that it has not been ordered, as none of the motorships now contemplated by the Shipping Board will show any advance over foreign motorships already in service, so if the fleet of 9800-ton vessels is built, we shall still be behind European engineers in development and progress. Surely we might make at least one attempt to go a stage in advance of our friends across the sea.

The Shipping Board and the Motorship

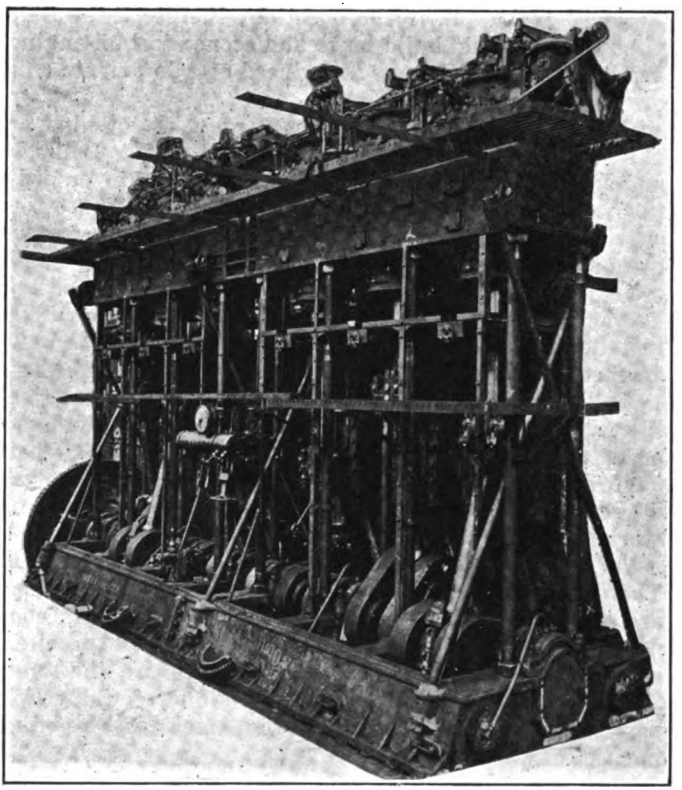
Toward the end of the war the Shipping Board Emergency Fleet Corporation gave some attention to the motorship, and in the summer of 1918 decided to build thirty-six "submarine-evading" cargo ships of special design, each of 5500 tons capacity, and for these vessels ordered fifty-two McIntosh & Seymour Diesel engines and twenty Skandia-Werkspoor Diesel engines, all of 750 to 850 b.hp. The hulls are now being redesigned, and 50 per cent of the order for the engines has been cancelled. In my opinion it was a very grave mistake on the part of the Emergency Fleet Corporation officials to make this large cancellation instead of changing part of the order to Diesel engines of at least double power, suitable for fast freighters of about 8000 to 10,000 tons dead-weight capacity. There is no logical excuse for this cancellation because, while it is true that many steam engine orders also have been cancelled, other steam sets are still being completed and installed in cargo vessels.

Under the revised shipbuilding program the Shipping Board proposes to build some 9800 tons capacity twin-screw motorships. They will have a speed of 13 knots and 4000 shaft hp. Orders for two twin-screw Diesel sets, each of 4300 i.hp., have already been placed by Mr. Hurley with Burmeister & Wain of Copenhagen, Denmark. There are rumors to the effect that many, if not all, of the engines for these ships will be of one design and may be constructed abroad but erected in the United States. Certainly no order has as yet been placed for engines for these particular ships with the two domestic firms that have had part of their order for Diesel engines cancelled. One may with reason inquire why their orders have been cancelled when engines are being purchased abroad. In America we can build an engine

Digitized by Google

equally as good as any foreign concern, for we now have the very latest European designs and technical information.

It is to be hoped that the Shipping Board will avoid making the mistake of "placing all its eggs in one bas-



A 1400-Hp. Dutch Diesel Engine

ket," and orders for these engines should be distributed throughout the shipbuilding and marine-engineering industry of the United States. At the present time there are excellent domestic facilities available for building successful designs of marine Diesel engines which were closed during the war, and I understand that several of

Digitized by Google

America's oldest and largest steel shipbuilders are now ready to accept such orders.

It is for the best interest of the nation that this be done without further delay if the Government is to follow up its widely announced intention to have the greatest mercantile marine in existence. If we should abandon this proposed plan, America will become the laughing stock of the world. A successful steam-propelled fleet is conceded to be out of the question; therefore the Shipping Board should build large and economical oil-engined motorships and sell them at reduced cost to private shipowners.

Outside of Great Britain the largest motorships are now being built in Sweden, Norway, Holland, Denmark and Japan. Some of those under construction or on order in Denmark are of 17,000 tons displacement, 12,470 tons capacity, 6000 i.hp. and 12½ knots speed. The engines are of the four-cycle Diesel type and each will have six cylinders of 740-mm. bore by 1150-mm. stroke, and will develop 3000 i.hp. at 115 r.p.m. Two engines will be installed per ship. Some of these vessels may be made smaller and thus have their speed increased to 15 knots.

At least a dozen of these companies have done very little in the way of actual commercial construction, but peace conditions now clear the way for them. Others have done a little work and then suspended or abandoned further development. Several have just made a start, but at least fifty have accomplished considerable naval or mercantile marine Diesel-engine construction. There are also several Japanese companies whose names are omitted. Among other American shipbuilding companies likely to undertake the construction of Diesel engines and motorships in the near future are the Ames Shipbuilding & Dry Dock Co., the Skinner & Eddy Corporation of Seattle, Wash., and the American Shipbuilding Co. of Cleveland, Ohio.

The two-cycle Sulzer and the four-cycle Werkspoor engines are being built by more firms than any other designs, namely, eleven and ten companies respectively. This is due to the large number of constructional licenses which both companies have sold.

In addition to these Diesel engine builders there are nearly 150 engineering concerns constructing surface-ignition, or the so-called "semi-Diesel" type marine heavy-oil engines, practically all of which operate on the two-cycle principle.

Digitized by Google

Performance of Early Motorships

In conclusion I wish to call your attention to the operation of the first two ocean-going Diesel-driven full-powered steel motorships. Although both were experimental ships, their performance has been better than that of many modern steamships. The tanker Vulcanus, placed in service in 1910, had up to a recent date logged 252,000 nautical miles at an average speed of 7 knots per hr. As she is only of 1215 tons dead-weight capacity, of 500 b.hp., and designed for a maximum speed of but 8 knots per hr., this is a splendid showing for a pioneer motorship. The other veteran motorship is the Selandia, placed in service early in 1912. She is of 7500 tons capacity and 2750 i.hp., with a designed speed of 10½ to 11 knots per hr. To date she has logged 327,737 nautical miles, at an average speed of 10.47 knots. During this time she has consumed 11,667 tons of fuel-oil and 59 tons of lubricating oil. Her total sea-time was 31,600 hr.

Marine Diesel Engine Builders

Excluding the central powers, there are eighty-six companies in the world building Diesel engines. Forty-two are building the four-cycle type; thirty-three, the two-cycle type, and eight, both types, with three firms uncertain.

NAME	CITY	DESIGN	CYCLES
	Norway		
Akers Mek-Vaerksted	Christiania	Burmeister & Wain	4
Norsk Maskinindustri Aktieselskab Thunes Mek-Vaerksted	Christiania	Sulzer	2
A/B Bofors, Gullspang	Karlskroga	Werkspoor	4
	Sweden		
Nya A/B Atlas Diesel Motorers	Stockholm	Polar	2 and 4
Gotaverken	Gothenburg	Burmeister & Wain	4
A/B Nobels Motorer	Stockholm	Hesselman	2 and 4
	Belgium		
Cockerill & Co.	Seraing	Burmeister & Wain	4
Carel Freres	Ghent	Carels	2
	Italy		
Gio Ansaldo & Co.	Genoa	Sulzer	2
Ansaldo San Giorgio	Turin and Spezia	Fiat-San Giorgio	2
Savoia Shipbuilding Co.	Cornigliano Ligure	Sulzer	2
Franco-Tosi, Ltd.	Legnano	Tosi	4
Ing. P. Kind & Co.	Turin	Kind	2
Officine Insubri Motori & Constructioni Meccaniche	Milan	Tosi or Langham & Wolff	4

Digitized by Google

NAME	CITY	DESIGN	CYCLES
	France		
Schneider & Cie	Paris and Creusot	Schneider	2 and 4
Chantiers et Ateliers de Nassaire (Penhoet)	Paris and St. Nassaire	Werkspor	4
Societe des Moteurs Chalassiere	St. Etienne	Sabathe	2 and 4
Thompson Houston Co.	Paris	Tosi	4
Forges et Chant ers de la Mediterreance	La Havre	Sulzer	2
Chantiers et Augustin Normand	Havre	Normand	4
Societe et Ateliers de la Loire	Nantes	Loire	4
Campagnie de Construction Mecanique Procedes Sulzer	Paris	Sulzer	2
*Weyher & Richemond	Paris	Werkspoor	4
*Dujardin et Cie	Lille	Werkspoor	4
Stabilimenti Delauney Belleville	St. Denis on Seine	Delauney-Belleville	4
	Holland		
Werkspoor Engineering Works	Amsterdam	Werkspoor	4
Werf Gusto, Firma A. F. Smulders	Scheidam	Gusto	4
	Denmark		
Burmeister & Wain	Copenhagen	Burmeister & Wain	4
Danish Diesel Motor Works	Holeby	Holeby	4
Hera Motorfabrik	Copenhagen	Hera	2
	United States		
Bethlehem Steel Co.	South Bethlehem, Pa.	West	2
Ingersoll-Rand Co.	New York, N. Y.	Price-Rathbun	4
Rathbun-Jones Engineering Co.	Toledo, Ohio	Price-Rathbun	4
Sterling Engine Co.	Buffalo, N. Y.	Sterling-Junkers	2
Worthington Pump & Machinery Corporation	Buffalo, N. Y.	Snow	4
Atlas Imperial Gas Engine Co.	Oakland, Cal.	Atlas	4
Midwest Engine Co.	Indianapolis, Ind.	Werkspoor and Midwest	4
Skandia-Pacific Oil Engine Co.	Oakland, Cal.	Werkspoor	4
Dow Pump & Diesel Engine Co.	Alameda, Cal.	Willans-Robinson	4
Wm. Cramp & Sons Ship & Engine Building Co.	Philadelphia, Pa.	Burmeister & Wain	4
McIntosh & Seymour Corporation	Auburn, N. Y.	Polar	4
Fulton Mfg. Co	Erie, Pa.	Fulton	2
Winton Engine Works	Cleveland, Ohio	Winton	4
Wisconsin Motor Mfg. Co.	Milwaukee, Wis.	Wisconsin-Junker	2
Nordberg Mfg. Co.	Milwaukee, Wis.	Carels	2
Busch-Sulzer Co.	St. Louis, Mo.	Sulzer	2 and 4
New York Shipbuilding Co.	Camden, N. J.	Werkspoor	4
Newport News Shipbuilding & Dry Dock Co.	Newport News, Va.	Werkspoor	4
New London Ship & Engine Co.	Groton, Conn.	Nelseco	4
Southwark Foundry & Machine Co.	Philadelphia, Pa.	Southwark-Harris	2
James Craig Engine Works	Jersey City, N. J.	Craig	4
Gas Engine & Power Co.	Morris Heights, N. Y.	Speedway	2
Manitowoc Shipbuilding Co.	Manitowoc, Wis.	Tosi	4
	Switzerland		
Sulzer Freres	Winterthur	Sulzer	2
	Japan		
Japanese Navy Department	Tokyo	Sulzer	2
Kawasaki Dockyard	Kiobe	Ansaldo-Fiat	2
	Russia		
Kolomna Mashinenfabrik	Golutwin	Sulzer and Kolomna	2 and 2
Nobel Maschinenfabriko	Petrograd	Nobel	2 and 4
Soromow Engineering Wrks	Soromow	Sulzer	4
	Spain		
Sociedad Espanola de Constructione Metalicas	Madrid and Bilbao	Sulzer	2

Digitized by Google

Great Britain

Cammell-Laird & Co.	Birkenhead	Fullagar	
[3]North British Diesel Engine Co.	Glasgow		4
Clyde Shipbuilding & Engineering Co.	Govan, Glasgow	Carels	2
Harland & Wolff Diesel Department	Glasgow	Burmeister & Wain	4
Wm. Doxford & Sons (Northumberland Shipbuilding Co., Ltd.)	Sunderland	Junkers Solid-injection	2
Wallsend Slipway	Wallsend-on-Tyne		
North Eastern Marine Engineering Co.	Wallsend-on-Tyne	Werkspoor	4
John I. Thornycroft & Co.	London	Carels	2
William Denny Bros. & Co., Ltd.	Dumbarton	Sulzer	2
J. Samuel White & Co.	East Cowes	White M.A.N.	2
Vickers Limited	Barrow-in-Furness	Vickers	4
Mirrlees, Bickerton & Day	Stockton-on-Tees	Mirrlees	4
Willans, Robinson & Co	Rugby	Willans	4
Yarrows Limited	Scotstown	M.A.N.	2
Fairfield Shipbuilding & Engineering Co.	Port Glasgow	M.A.N.	2
Scotts Shipbuilding & Engineering Co.	Greenock	Fiat	2
Alex. Stephen & Sons	Linthouse Glasgow		
Sir W. G. Armstrong Whitworth & Co.	Newcastle-on-Tyne	Armstrong-Whitworth	2 and 4
Richardsons Westgarth	Middlesbrough	Carels	2
William Beardmore & Co., Ltd.	Dalmuir	Beardmore and Tosi	4
Swan, Hunter & Wigham Richardsons, Ltd.	Newcastle-on-Tyne	Neptune and Polar	2
Palmers Shipbuilding & Engineering Co.	Jarrow-on-Tyne		
Barclay, Curle & Co.	Glasgow	Burmeister & Wain	4
Norris, Nenty & Gardners, Ltd.	Paticroft	Gardner	4
Union Ship Engineering Co., Ltd.	Montrose		4
Ruston & Hornsby	Lincoln	Nelseco[4]	4

[3]Stationary engines only.
[3]Originally formed to build Krupp engines.
[4]Several other British engineering companies also built the Nelseco (American) marine Diesel engine during the war.

Digitized by Google

MID-WEST SECTION PAPERS

LUBRICATION AND FUEL TESTS ON BUDA TRACTOR TYPE ENGINE

By P J Dasey[1]

THE rapid development of heavy-duty trucks and farm tractors has made it necessary for manufacturers of engines used in such automotive apparatus to face problems regarding which there is no past experience to fall back upon. The necessity in both types of engine for maximum strength in all parts carrying excessive loads constitutes a problem of great importance, but in addition to it are others of the proper utilization of fuels at present available, lubrication under excessive load conditions over long periods of time; and, of nearly as much importance, the relation of fuels to lubricants and the effect of fuels upon lubricants. Moreover, information is to be acquired regarding the value of prospective fuels as power producers, the effects they have upon engines, lubricants, etc., comparisons of cost and the like. The tests recorded in the paper were made in an endeavor to ascertain some of these unknown values.

The demand for heavy-duty engines of the four-cylinder, four-cycle, vertical type, especially for use in farm tractors, has made it necessary to alter design with the idea not only of strengthening such parts as are under maximum load conditions during practically all of the operating period but also of allowing for adjustments to shaft and connecting-rod bearings with the least loss of time and effort.

The Buda HTU model engine illustrates late development in medium size, four-cylinder engines produced for use in farm tractors and heavy-duty trucks.

In exterior appearance it differs from the conventional type only in the detachable head and split oil-pan, two features that are highly valuable in tractor work where the excessively heavy duty makes it necessary that ac-

[1]Sales and research engineer, Buda Co., Harvey, Ill.

Digitized by Google

cess to cylinders, valves and crank bearings be easy as well as rapid.

The general dimensions of the engine are as follows:

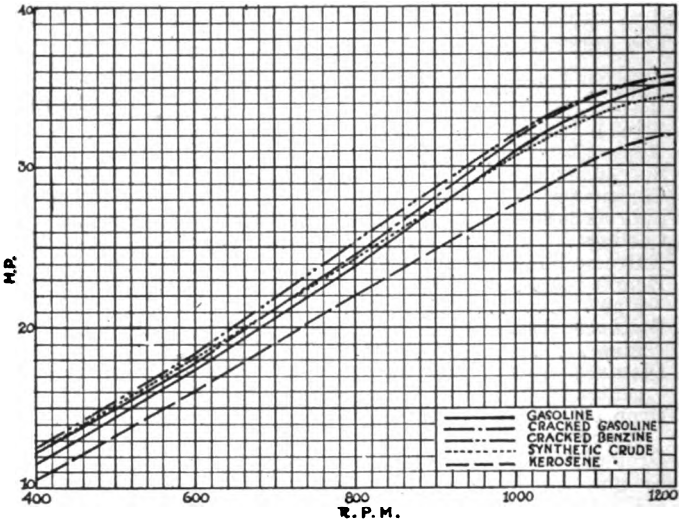
Type	4-cylinder, vertical, in block L-head, 4-cycle
Bore	4¼ in.
Stroke	5½ in.
Approximate weight, with regular equipment	800 lb.
Suspension	Three-point
Carbureter	1¼ in. vertical outlet
Lubrication	Geared pump force-feed system
Cooling	Centrifugal water pump
Extreme length of crankshaft	32 1/16 in.
Height from center of crankshaft to top of water outlet pipe	25¼ in.
Distance from center of crankshaft to bottom of engine	9 11/16 in.
Distance from center of front supporting bracket to center of rear supporting arm	34 3/16 in.
Drop of supporting arms from center of crankshaft to top of frame	4 to 6 in.
Drop of front support bracket	2½ or 3½ in.
Length of rear supporting arm	25¾ in.
Length of engine over cylinders	24⅞ in.
Diameter of flywheel	17 in.
Weight of truck flywheel	76 lb.
Weight of tractor flywheel	115 lb.
Face of flywheel	3½ in.
Flywheel regularly furnished for multiple-disk clutch.	
Diameter and length of front bearing	2⅛ x 3⅛ in.
Diameter and length of middle bearing	2¼ x 2¾ in.
Diameter and length of rear bearing	2⅜ x 4 in.
Diameter and length of connecting-rod bearings,	2⅛ x 2½ in.
Connecting-rod length from center to center	12¼ in.
Number of connecting-rod bolts	4
Diameter of connecting-rod bolts	7/16 in.
Diameter and length of piston-pin bearings	1⅛ x 2⅛ in.
Length of piston	5⅜ in.
Effective working diameter of valves	1⅞ in.
Piston displacement	312 cu. in.
Internal diameter of bell housing flange	16⅛ in.
External diameter of bell housing flange	17¾ in.
Diameter of bolt circle	16⅞ in.
Diameter of bolts	⅜ in.

The split oil-pan is a feature which has proved highly valuable in practice, as it permits of the bearings being examined and adjusted without the necessity of removing the transmission from the bell housing.

The valve timing is as follows: Inlet opens 15 deg. past top center and closes 40 deg. past bottom center, while the exhaust opens 45 deg. before bottom center and closes 10 deg. past top center.

While this valve setting has worked out well in prac-

Digitized by Google



HORSEPOWER DEVELOPED AT DIFFERENT SPEEDS BY FOUR FUELS

tice it has not by any means been determined that it is the most efficient; hence further experimentation is being carried out which it is hoped will ultimately determine what change if any is necessary in the timing to secure maximum results in the use of fuel as well as in life of valves.

The intake valve areas have been designed for the high velocity of the ingoing mixture. At 600 r.p.m. the velocity is 6033 lineal ft. per min.; at 800 r.p.m., 8044; at 1000 r.p.m., 10,055, and at 1200 r.p.m. 12,066 lineal ft. These figures are based on calculation only. The vacuum readings at the same speeds are at 600 r.p.m. 0.45 in.; at 800 r.p.m. 0.80 in.; at 1000 r.p.m. 1.25 in., and at 1200 r.p.m. 1.60 in.

The water-pump is of the ordinary rotary vane type with a capacity of 4½ gal. at 400 r.p.m.; 8½ gal. at 700 r.p.m.; 11 gal. at 900 r.p.m., and 14 gal. at 1200 r.p.m.

The projected area of the wrist-pin bearing is 2.39 sq. in. (1.125 in. by 2.125 in.), carrying a total pressure of 2001 lb., or approximately 837 lb. per sq. in. The projected areas of the main bearings are: front main bearing, 6.7 sq. in., load approximately 720 lb. per sq. in.; center main bearing, 6.18 sq. in., load approximately 780 lb. per sq. in.; rear main bearing, 9.49 sq. in., load ap-

Digitized by Google

proximately 518 lb. per sq. in. Total of all main bearings—22.37 sq. in. with an average pressure of 672⅔ lb. per sq. in. Ratio to piston displacement 13.5 to 1.

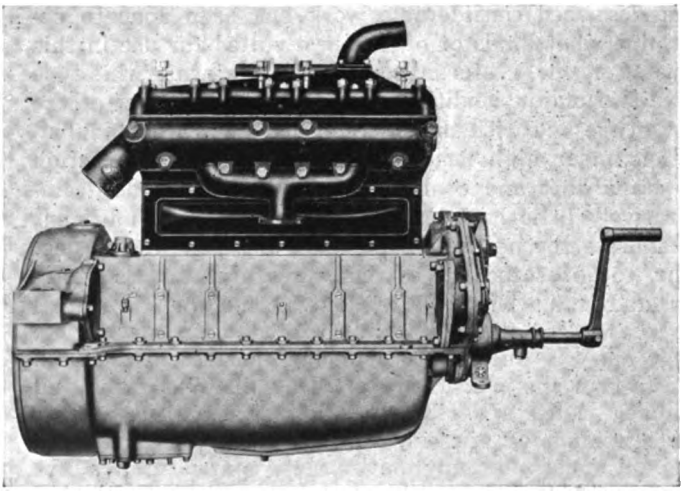
The connecting-rod bearings each have 5.31 sq. in. with a pressure per sq. in. of 908 lb.

The valves have semi-steel heads electrically welded to 0.20 carbon, 7/16-in. diameter stems. They lift 5/16 in. and have 1⅞-in. diameter in the clear. The camshaft, 1 in. in diameter, and cams are turned out of solid bar, cams being ¾ in. wide. There are three bearings of ample proportions.

The crankshaft is made of 0.45 carbon open-hearth steel; the connecting-rods of 0.25 carbon open-hearth steel.

A pressure lubrication system is used which forces the lubricating oil to all crankshaft, crank-pin, wrist-pin and camshaft bearings, the pressure ranging from 0 to 30 lb. at 1000 r.p.m.

The pressure is furnished by a gear pump mounted on the bottom and at the rear end of the oil-pan and driven by spiral gears mounted on the cam and pump shafts. The oil is carried in the oil-pan and before reaching the pump must pass through a bronze wire screen mounted near the center of the oil-pan, after which it enters a pas-



A Medium Size Four-Cylinder Engine Recently Developed for Farm Tractors and Heavy-Duty Trucks

Digitized by Google

sage leading to the intake side of the pump. From there it is forced up a passage-way leading to a tube which runs the length of the engine and from which passage-ways lead to the main and camshaft bearings. From the main bearings the oil is fed to the crank-pins through holes drilled through the crankshaft and from the connecting-rod bearings to the wrist-pin bearings, through copper tubes clamped to the sides of the connecting-rods. The cylinders are lubricated by the oil thrown off the connecting-rod bearings at the crank-pins, while the cams, push-rods, tappets and valve-stems are lubricated by oil thrown by the cams and cranks to the guides above.

A relief valve is provided in the main oil line at the front of the engine so that when the pressure reaches the point at which the spring is set to operate, the ball check is raised and the oil flows into the front gear-case, thus furnishing a constant supply of oil to the gears. To hold a constant reservoir of the oil in the gear-case a small dam is cast across the outlet so that the oil level is always above the bottom of the gear mounted on the engine shaft.

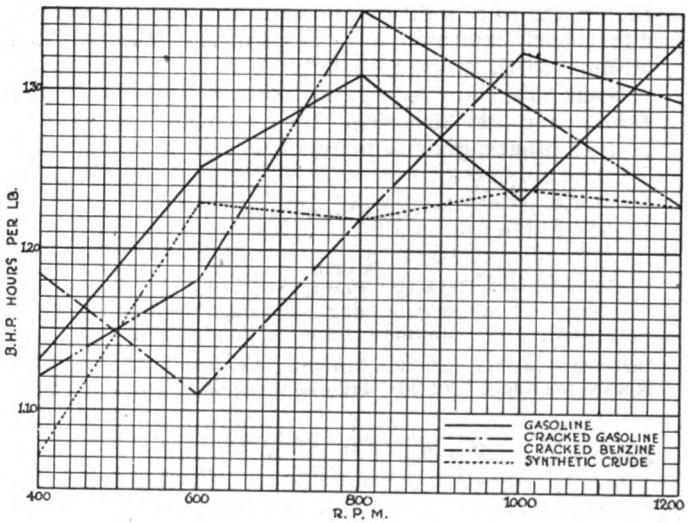
Lubrication

In connection with the work already accomplished in the designing and working out of the full pressure system described considerable work has been done to determine what kinds of oil are best suited for use in this type of engine. Internal-combustion engines of this type have two major conditions in lubrication to meet at the same time and with the same oil, namely, cylinder lubrication under high heats and pressures, and lubrication of crankshaft and connecting-rod bearings under comparatively little heat but high pressure. The lubricant must have the necessary body and viscosity at 150 deg. fahr. to withstand the extreme pressures in the crank-pin and main bearings without permitting the metal surfaces to come in contact; also its viscosity at 350 deg. fahr. must be such as to provide a perfect piston seal, and to bear the pressures exerted against the piston and cylinder walls, under very high heat conditions, with the minimum of cracking or decomposition of the oil. The oil must not only have these characteristics but must be fluid at reasonably low temperatures, although for pressure-feed types the cold test is not so important

Digitized by Google

as far as feeding the lubricant in cold weather is concerned.

As a general rule oils of low gravity crack under lower temperatures and pressures than do oils of higher gravities, the result being more rapid consumption of the oil, partly as fuel, partly in the formation of carbon deposits in the cylinders, and partly in the increase of the heavy tarry ends washed down into the reservoir. The more a given oil decomposes, the less its value as a lubricant becomes. Some of the heavier vapors condense and are washed down with the heavy tarry ends, thus raising the gravity (making the oil lighter) and lowering the flash and fire points to a considerable degree. This condition makes rapid consumption of the lubricant unavoidable and causes considerable difficulty with carbon deposits on plugs, cylinders, pistons and rings. If continued in use for any great time the crankcase oil will become a thick tarry mass, too heavy to circulate freely and dangerous to use.



POWER DEVELOPED PER POUND OF FUEL

The lighter gravity oils are usually subject to a higher degree of evaporation and a lesser degree of cracking; hence to get a satisfactory lubricant that will serve both cylinder and bearing conditions with the least decompo-

Digitized by Google

sition, maintaining with the highest flash and fire points the viscosity from which the best average results can be expected, characteristics have been tabulated.

Oils specified for summer use only are much heavier in body than those specified for all-year service, and while they may be used in summer only because of their remaining in a fluid condition, they will carbonize more freely than the lighter oils. They are more viscous, however, and will carry the loads placed upon them with less wear of the bearings than the lighter oils. It is a matter of choice which oil one uses, all things considered. One reason for not using heavy oils in winter is that they become very thick at low temperatures and hold the pistons so tightly that considerable power is required to start them.

Gravities do not play an important part in the selection of an oil. The principal points to judge by are the flash and fire points and the viscosities at both 150 and 350 deg. fahr. While the crankcase oil will vary also in temperature under different working conditions, in winter and summer, the point of 150 deg. fahr. has been taken as a basis of calculation, while 350 deg. fahr. more nearly approximates the condition under which the oil must work in the cylinders.

Some oils show high viscosities at 150 and 212 deg. fahr., but at 350 deg. fahr. greatly reduced viscosity; others give ordinary readings at the first and

OIL SPECIFICATIONS

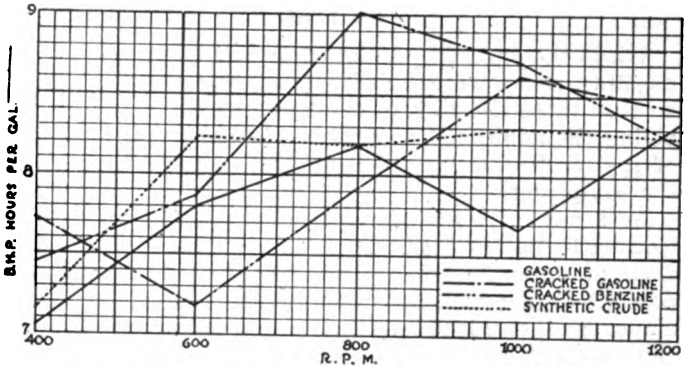
Oil	Gravity, deg., Baumé	Flash Point, deg., fahr.	Fire Point, deg., fahr.	Viscosity at 212 deg. fahr., sec.	Viscosity at 350 deg. fahr., sec.
[2]All-year	20-30	415-465	455-520	58- 85	36-40
Heavy summer.	22-29	470-530	530-600	100-125	40-45

[2]The cold test for these oils is preferably 20 to 25 deg. fahr. and should not exceed 32 deg.

second temperatures and drop but little at the third.

The best results will be obtained from an oil that, all other things being equal, shows the greatest viscosity at both 150 and 350 deg. fahr. In other words, an oil having the proper cold test, flash and fire points and the greatest viscosity at 150 and 350 deg. fahr.

Digitized by Google



POWER DEVELOPED PER GALLON OF FUEL

will give far better service as a lubricant under heavy-duty working conditions than an oil as good in all other respects but with a relatively low viscosity at 150 deg. fahr., although the latter might have the same viscosity at 350 deg. fahr., which of course is not likely to happen.

There is such a difference in oils that it is impossible to tell without actual tests or a complete, dependable table of characteristics, including viscosities at 350 deg. fahr., just which kinds will best serve a particular purpose, but the day is coming when more attention will be given to this part of the engine business and a means found of giving the needed information to engine owners.

It will be noted that in the specifications tabulated there is considerable leeway in all characteristics except the viscosity at 350 deg. fahr., universal Saybolt viscosimeter, where the limits are rather close. The oils which come within these limits naturally have the desired characteristics at the lower temperature, and flash and fire points; hence it is important that in addition to the other characteristics the viscosity at 350 deg. fahr. and a cold test be obtained.

These data are based on the requirements of an engine of the type described, in which the oil is used for lubricating all bearings as well as the cylinders, and should not be confounded with specifications that might be deemed desirable for an oil to be used in engines of other types. It was because of the excessively heavy duty this type of engine is called upon to perform that investigation of the oil problem was made. Considerable work remains to be done in this connection.

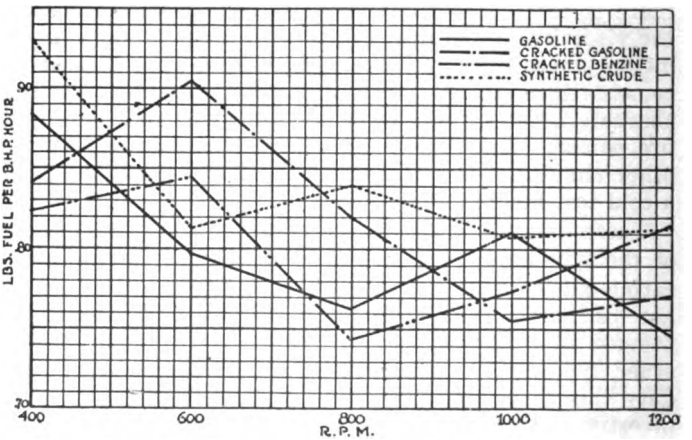
Digitized by Google

Fuel Tests

While the engine is designed primarily for the use of gasoline, it can be provided with a low-compression head so that those desiring to use kerosene can do so by applying the additional apparatus adapted to the handling of that fuel. This is not furnished as a regular part of the equipment.

As a part of the research work carried on in connection with the HTU engine, tests were made of cracked fuels of different weights to determine whether it was possible to use such fuels in an engine of this type, designed and equipped for the use of gasoline. The results are given in Table 1. The plotted curves will more readily illustrate the results obtained. The tests were made with a regular Stromberg carbureter attached to a gasoline manifold. No hot-air stove or other means of heating was provided; in fact it was the regular gasoline equipment. A Sprague electric cradle dynamometer was used, with all the necessary equipment for weighing the fuel, counting the revolutions, timing, taking the temperature of water inlet and outlet, as well as the oil temperature in the crankcase, manifold, vacuums, etc.

This sheet shows the horsepower curves of all five tests, including the kerosene test, which was made with a low-compression head and heated manifold, but without hot air being taken through the carbureter. This particular test was made only for horsepower determina-



Fuel Consumption in Pounds Per Brake Horsepower Hour

Digitized by Google

TABLE I—FUEL TESTS WITH 1 LB. OF EACH

Engine Used—Buda HTU—High-Compression Head—Gasoline Manifold—Four Cylinders—4.25 by 5.50 in.—Water 120 to 150 deg. fahr.—Barometer 29.5 in.

Fuels Used

	Gravity, deg. Baumé	Specific Gravity	Lb. per gal.	Gal. per lb.	Approx. B.t.u. per lb.	Approx. B.t.u. per gal.	Init. Boil'g Pt. deg. fahr.	End Point deg. fahr.	Composition, per cent: Gasoline	Kerosene	Heavy Distillate
Commercial gasoline	56.9	0.7491	6.236	0.1604	18,569	115,796	128	429	54.0	39.0	2.0
Cracked gasoline	49.3	0.7808	6.501	0.1538	18,493	120,223	120	393	46.5	49.5	3.0
Cracked benzine	44.8	0.8009	6.668	0.1500	18,494	120,224	120	423	23.0	73.5	3.5
Synthetic crude	44.0	0.8046	6.699	0.1493	18,440	123,530	120	454	31.0	65.0	3.5

Duration of run Min.	Sec.	R.P.M.	Load lb.	B.Hp.	B.Hp. per rev.	R.P.M.	B.Hp.	Internal friction Hp.	I.Hp.	Total lb. fuel per hr.	Total fuel gal. per hr.	Lb. per b.hp.hr.	Gal. per b.hp.hr.	B.hp. hr. per lb.	B.hp. hr. per gal.	Average b.hp.hr. per gal.
Test With Gasoline																
5	55	391.0	88.0	11.46	0.2930946	400	11.62	0.80	12.42	10.14	1.6260	0.88489	0.13993	1.1300	7.04663	
4	23	591.5	87.0	17.14	0.2895270	600	17.37	1.87	19.24	13.69	2.1950	0.79860	0.12220 pls	1.2520	7.79500	
3	23	780.0	89.5	23.26	0.2982000	800	23.86	3.33	27.19	17.73	2.8430	0.76240	0.12220 pls	1.3118	8.17000	7.80
2	25	988.0	93.0	30.62	0.3099190	1,000	30.99	4.66	35.65	24.83	3.9810	0.81090	0.13000 pls	1.2330	7.68890	
2	16	1,200.0	88.5	35.39	0.2949166	1,200	35.39	6.40	41.79	26.47	4.2447	0.74795	0.12000	1.3369	8.33700	
Test With Cracked Gasoline																
5	49	400	92.0	12.26	0.3065000	400	12.26	0.80	13.06	10.32	1.5784	0.841360	0.1295000	1.188	7.723188	
3	46	590	89.5	17.59	0.2981356	600	17.89	1.87	19.76	15.93	2.4500	0.905628	0.1392800	1.104	7.177104	
3	1	787	92.5	24 26	0.3082590	800	24.66	3.33	27.99	19.89	3.05968	0.820000	0.1261200	1.220	7.931220	7.97
2	32	993	95.0	31.43	0.3165166	1,000	31.66	4.66	36.32	23.68	3.64000	0.753400	0.1158129	1.127	8.626827	
2	11	1,200	89.0	35.59	0.2965883	1,200	35.59	6.40	41.99	27.48	4.22700	0.772000	0.1187000	1.295	8.418795	
Test With Cracked Benzine																
5	57	395	93.0	12.24	0.309873400	400	12.39	0.80	13.19	10.08	1.512	0.8239	0.1235300	1.120	7.468160	
3	56	588	92.0	18.03	0.306632653	600	18.40	1.87	20.27	15.25	2.287	0.8460	0.1268000	1.182	7.881576	
3	16	785	94.5	24.72	0.314900000	800	25.19	3.33	28.52	18.37	2.775	0.7430	0.1122600	1.350	9.001800	8.23
2	29	983	95.5	31.28	0.318200000	1,000	31.82	4.66	36.48	24.16	3.623	0.7720	0.1158248	1.294	8.628392	
2	5	1,193	89.0	35.38	0.296563285	1,200	35.59	6.40	41.99	28.80	4.319	0.8140	0.1220700	1.230	8.201640	
Test With Synthetic Crude																
5	17	399	91.8	12.20	0.305764400	400	12.23	0.80	13.03	11.36	1.6960	0.93085	0.13900	1.07	7.16793	
4	10	584	91.0	17.21	0.303253424	600	18.20	1.87	20.07	14.40	2.1495	0.81300	0.12190	1.23	8.23977	
3	2	780	91.5	23.78	0.304871800	800	24.39	3.33	27.72	19.78	2.9540	0.84000	0.12426	1.22	8.17278	8.02
2	28	983	92.0	30.13	0.306510680	1,000	30.65	4.66	35.31	24.32	3.6450	0.80730	0.10106	1.24	8.30676	
2	11	1,181	86.0	33.84	0.286536830	1,200	34.38	6.40	40.73	27.48	4.1020	0.81200	0.12120	1.23	8.23977	

Digitized by Google

tion and no record was kept of fuel consumption per brake horsepower per hour.

The accompanying table gives the relative rank of the various fuels at different speeds.

Fuel	Speed, r.p.m. 400	600	800	1000	1200
Cracked benzine	1	1	1	1	1
Cracked gasoline	2	3	2	2	2
Synthetic crude	3	2	3	4	4
Ordinary gasoline	4	4	4	3	3
Ordinary kerosene	5	5	5	5	5

It will be noted that ordinary gasoline produced less power than any one of the three cracked fuels at all speeds, except at 1000 and 1200 r.p.m., at which point it moved into third place as a power producer, synthetic crude dropping to fourth position.

In all cases the cracked benzine and the cracked gasoline show power-producing quality superior to that of ordinary gasoline under exactly the same operating conditions. In each test the engine was speeded up to 1000 r.p.m. with full load, at which point the carbureter was adjusted for maximum power, after which the test was started at 400 and continued up to 1200 r.p.m. with no further adjustments.

It is but fair to say that the kerosene test, which was made with a low-compression head, about 10 lb. lower than that of the other head used, does not compare favorably as to power developed. No special vaporizer or heating apparatus, other than the heated intake manifold, was added, and a regular Stromberg carbureter was used, as in the other tests. It was not to be expected that the showing would be what the fuel is capable of when properly handled. The power curve is given merely to show what kerosene will do in the engine with no special treatment other than the heated manifold to assist vaporization. The reasons, outside the low-compression head, for the falling off of power in the kerosene test are the loss in volumetric efficiency owing to the use of the heated manifold and the slow burning of only a part of the charge owing to lack of complete gasification.

THE DISCUSSION

The discussion brought out the fact that good air cleaners will eliminate much repairing and many worn-out bearings, and that the chief reason for making the

Digitized by Google

tests was to discover what was happening in the crankcase to cause so many burned-out bearings. The Buda service men were requested to send in samples of the crankcase oil in all cases of engine trouble, and in these a large proportion of dirt was found.

Mr. Dasey cited one instance of a 4½ by 6-in. engine which was used in a 5-ton truck and in which six sets of bearings had been burned out in six weeks. The owner of the truck claimed that the engine was defective, but the oil showed 100 cc. (6 oz.) of sand. In addition to the sand, ¾ in. of mud was found on the bottom of the case after it had stood over night. Further investigation proved that the owner, who was a contractor, used his truck for hauling crushed stone. It was a 5-ton truck but hauled 8 tons every trip. As he ran his truck onto the stone crusher and dumped the stone in, the engine took in all the dust. The oil used was of a grade suitable for passenger cars in summer time.

In regard to the synthetic crude fuel, Mr. Dasey said it would make an ideal fuel for tractors when properly handled, and for engines of medium or low speeds. Heavy-gravity material should not be used in high-speed engines. He thought it would be possible to make use of the synthetic crude in passenger car engines.

Digitized by Google

THE HIGH-COMPRESSION OIL ENGINE

By W G Gernandt[1]

THE ever-increasing demand for highly volatile fuels and constantly decreasing volatility, constitute a serious problem. Synthetic fuels have been suggested as a remedy, but these require a change in carburetion methods. It is the author's conviction that, if any redesigning is necessary, this should embody a combustion method by which any of the existing liquid hydrocarbons can be utilized and further change of method obviated, if a new fuel should later be developed.

The high-compression engine is presented as a solution. Proof is offered that by its adoption any liquid hydrocarbon fuel can be utilized under any temperature condition and a real saving in fuel accomplished through increased thermal efficiency. Sustained effort should be made along these lines to increase thermal efficiency and provide an engine of adequate power, flexibility, ease of control and ability to operate on any of the fuels obtainable now or later.

The necessity of providing suitable means to burn the heavier oils in internal-combustion engines successfully is being slowly but surely brought home to designers and builders of automotive apparatus, and the time seems opportune for making a comparison of the various methods of injecting liquid fuel into the combustion chamber of an engine, with a view to impressing upon engineers the need of using the high-compression type of engine for the proper burning of the heavier oils.

To really show the advantage of high compression, it will be necessary to describe in detail in a somewhat semi-technical way the cycle of events taking place in the Otto, or constant-volume engine, as well as the Diesel, or practically constant-pressure engine.

Four-Stroke Constant-Volume or Otto Engine

The Inspiration Line AB At the end of the exhaust stroke, *E-F-A*, Fig. 1, the clearance volume V_c is filled with burned gases under a pressure of P_e. When the

[1]Vice-president and general manager, Gernandt Motor Corporation, Chicago, Ill.

Digitized by Google

piston moves on its inspiration stroke the pressure falls from P_e to the inspiration pressure P_i along a curve determined by the reexpansion of the products of combustion remaining in the combustion chamber at the time the exhaust valve closed. Only after the reexpansion will the fresh charge be drawn into the cylinder. It is thus seen that the volumetric efficiency E_v of the cylinder, which equals the ratio of volume of fresh charge to the volume of piston displacement, depends directly upon the volume and pressure of the burned gases remaining in the cylinder or combustion chamber. If through a poor design of combustion chamber, too small an exhaust valve, faulty valve-timing or a restricted exhaust manifold, the exhaust pressure should remain too high, the effect of reexpansion before actual inspiration will be greatly increased. However, with a properly designed engine this loss in volumetric efficiency will be low and depend directly upon the actual volume of the combustion chamber.

Another factor affecting this efficiency is the inspiration pressure P_i. At the end of the inspiration stroke the cylinder contains a volume of gas V_i made up of products of combustion and a fresh charge under a pressure of P_i. The compression stroke raises the pressure of this gas to P_c at a volume of V_c. The compression curve BC crosses the atmospheric line XX at G when the stroke volume is only V_{si} and not the full volume V_s. Hence, the volume $V_s - V_{si}$ represents a loss in volumetric efficiency which is greater as P_i becomes smaller. Therefore, in order to keep this efficiency high, inlet pipes and valves should be of such size as to reduce the inspiration friction to a minimum, thereby keeping the inspiration pressure as close to the atmospheric line as possible. A volumetric efficiency in excess of 100 per cent could be obtained if it were possible to force the charge into the cylinder at a greater pressure than atmospheric. It is well to note also in this regard how the carbureter reduces the volumetric efficiency: (*a*) To atomize the fuel properly it is necessary to choke the air at the spray nozzle so as to increase the gas velocity at this point. This causes an increased friction, thereby decreasing the value of E_v. (*b*) With the present low grade of fuel it is necessary to add heat to the intake air to increase the atomization of the fuel. This is done by drawing the air supply from a jacket surrounding the exhaust pipe. Naturally the value of E_v is reduced because of the reduced weight of the charge and the in-

Digitized by Google

creased friction in inlet pipe. (*c*) At reduced speeds and powers the throttle-valve of the carbureter is partly closed, causing increased friction and a reduction of the inspiration pressure P_i. Thus, it is seen that the value of E_v is reduced by an increase of compression space, the use of a carbureter and the necessity of using heat to atomize properly the poor grade of fuel now on hand.

The Compression Line BC The compression line may be taken to follow the general law of pv^n = constant. In other words, the pressure is increased in a certain proportion to the decrease in volume, depending upon the kind of gas compressed, the temperature of the gas at the beginning of compression and the amount of heat given to or taken from the cylinder walls. For air the value of n is 1.41, but for a mixture of fuel and air it varies from 1.30 to 1.38, with a good average for actual conditions of 1.35. As the thermal efficiency of an engine increases slightly with an increase in the value of n, it is seen that in compressing pure air a decided advantage would be gained.

It has been proved that the thermal efficiency of an engine depends upon the pressure at the end of compression. The higher this pressure the higher the efficiency and, consequently, the greater the fuel economy. In a constant-volume, or Otto engine, the explosive mixture is compressed in the combustion chamber; therefore, the limit of compression pressure is the preignition point of the mixture. For gasoline the compression pressure can be safely carried to 100 lb. per sq. in., while for kerosene the pressure must be reduced to about 65 lb., showing not only a loss in thermal efficiency, but a loss in power output as well when using kerosene for fuel in this type of engine.

The Combustion Line CD The shape of this line depends upon the composition of the fuel mixture, the point of ignition and the piston speed, presupposing a properly designed combustion chamber. The fuel mixture composition depends upon the kind of fuel used, and the proper commingling of the fuel and air. This commingling is the function of the carbureter and upon its proper adjustment depends the explosibility of the charge. A too rich or too weak mixture causes the burning to lag and the maximum pressure obtainable from the fuel will be greatly reduced. The point of ignition plays an important part in the shape of the combustion line in that should the ignition be late, not only is the maximum

Digitized by Google

pressure in the combustion chamber reduced but instead of the combustion line being vertical it will fall away as shown in the dotted line in Fig. 1. If the ignition be too early, the pressure rise will occur before the piston has reached its dead center on the compression stroke, and a decided loss in power and economy and a great strain on the crank bearings will result. It is therefore essential to have ignition occur at the proper point. Piston

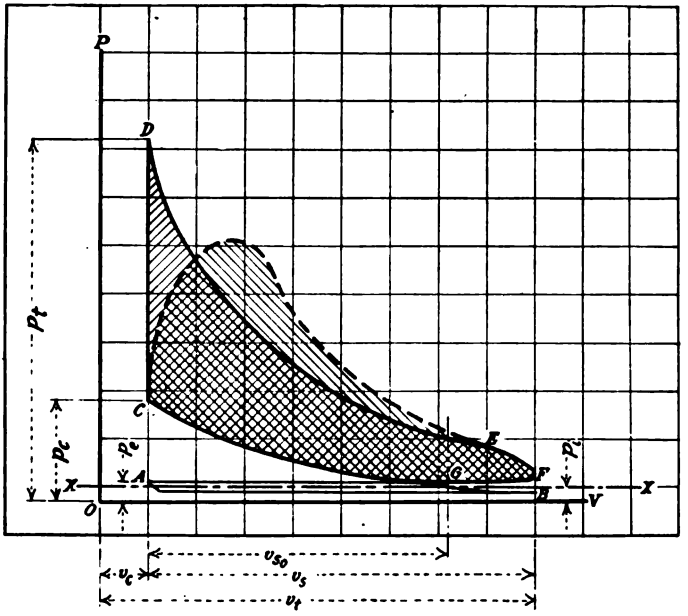


FIG. 1—P-V DIAGRAM FOR OTTO CYCLE ENGINE
The Shaded Area Indicates Work Done

speed also affects the combustion line in that with an increase in speed the combustion must take place at a greater rate and therefore the ignition point must be advanced to maintain maximum power and economy conditions.

The Expansion Line DE The expansion line, like the compression line, follows the general law of pv^n = constant, but the value of n is approximately 1.38 because the burned gas resembles air more closely than does the mixture during compression. As in the com-

Digitized by Google

bustion line, the quality of mixture, time of ignition and piston speed have a great bearing upon the expansion line. However, other conditions such as cooling and length of stroke also play a part in the power output and fuel economy, but with proper design they are of less importance.

The Exhaust Line EFA This line is dependent upon the size of the exhaust ports and the exhaust valve-timing. It is absolutely essential to allow for the most rapid drop in exhaust pressure to atmospheric to insure the lowest possible value for P_e, thereby increasing the volumetric efficiency, as shown under the inspiration line.

The requirements for best efficiency of combustion and expansion have been stated briefly, but in greater detail they are as follows:

(1) Highest possible compression before ignition. The effect of this is
- Reduced combustion chamber with a reduced admixture of products of combustion
- Less heat loss to water-jacket because of reduced combustion chamber
- Greater mean effective pressure for the power stroke
- Lower terminal or exhaust pressure and exhaust loss
- Greater ease of ignition of the charge

(2) Pure uniform mixture and rapid combustion to avoid after-burning with a consequent loss to the water-jacket

(3) Proper piston speed and bore-stroke ratio to keep the jacket loss as low as possible

(4) Reduction of inlet and exhaust friction to the utmost

(5) Proper valve-timing

The Diesel or High-Compression Engine

The Inspiration Line AB As in the constant-volume cycle there remain in the combustion chamber products of combustion at a pressure of P_e, and this gas must be reexpanded before inspiration can take place. However, it will be noticed that this reexpansion takes place at a more rapid rate, as the volume of combustion chamber is greatly reduced because of the greater compression required for this type of combustion.

The next point to be considered is the inspiration pressure P_i. In this case the same conditions govern the value of P_i as in the constant-volume engine, with the exception that pure air is drawn into the cylinder instead of a mixture of fuel and air formed by the carbureter. It is instantly seen that in eliminating the

Digitized by Google

carbureter the suction friction is reduced, the temperature of the air is not increased and the throttle friction at decreased speeds and powers is entirely eliminated, because engine control is produced by varying the amount of fuel supplied during combustion. Therefore, pre-

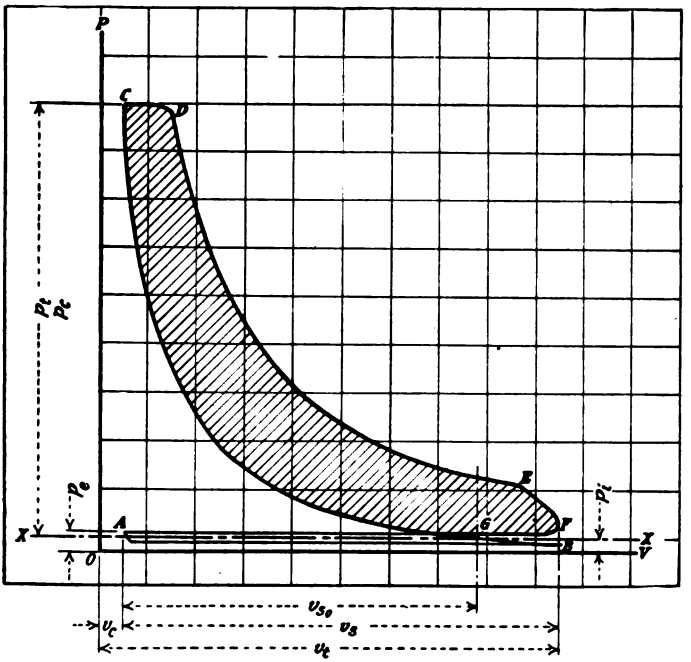


FIG. 2—P-V DIAGRAM FOR DIESEL ENGINE
The Shaded Area Indicates Work Done

supposing equal-sized valves in both cases, the value of P_i will more nearly equal atmospheric pressure in the case of the constant-pressure engine, as shown in Fig. 4.

The Compression Line BC The compression line follows the same general law as in the constant-volume engine (pv^n = constant), but the value of n reaches 1.41, which allows for a slightly increased thermal efficiency.

As pure air is compressed, preignition is not the limiting factor in determining the compression pressures, and pressures as high as 600 lb. per sq. in. can be used. However, as this great pressure causes an increase in

Digitized by Google

the weight of the various parts out of proportion to the gain in thermal efficiency, 500 lb. is considered a good limit of compression for this type of engine. Thus the main point in increased thermal efficiency has been gained without restriction as to fuel used or preignition.

The Combustion Line CD Aside from the high-compression feature, the combustion line differs considerably from the constant-volume engine and requires further attention. Instead of igniting a mixture of fuel and air electrically with an attendant sudden rise in pressure, the fuel is injected into an atmosphere of highly compressed and heated air when the piston reaches the upper dead-center, causing the fuel to be burned in suspension, or as it enters the air. This method of burning causes a slight rise or reduction in pressure during combustion, depending upon the rate of injection and the thoroughness of the atomization. While it is not possible to increase the combustion pressure in as great a ratio as in constant-volume combustion, considerable increase can be obtained depending upon the method of injecting the fuel. If the injection is relatively slow and takes place over a considerable portion of the power stroke, the pressure will drop. As the injection rate is increased the pressure drop decreases until a rate is reached where a decided increase in pressure during combustion is noted. The various methods used to inject fuel into the combustion chamber will be described in detail later.

The Expansion Line DE As in the case of the constant-volume engine, the expansion line follows the general law pv^n = constant, with the value of n equaling approximately 1.38 as in the previous case. However, due to the high pressure attained during compression, the rate of expansion is greater in this case and therefore the pressure in the cylinder at the time the exhaust valve opens is lower. The effect of this is to reduce the temperature and consequently the heat loss during exhaust. This means an increase in thermal efficiency.

The Exhaust Line EFA This line is similar to the exhaust line in a constant-volume engine, but as the pressure and temperature at the time of exhaust-valve opening are lower, there is a slight difference in the value of P_e. However, in actual practice the difference is so slight that it is very difficult to measure its value.

From the foregoing it is seen that the high-compression type of internal-combustion engine more nearly ap-

Digitized by Google

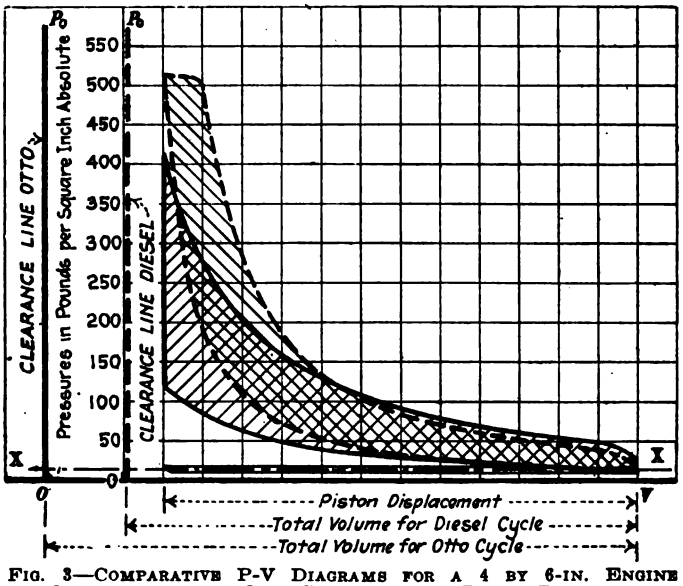


FIG. 3—COMPARATIVE P-V DIAGRAMS FOR A 4 BY 6-IN. ENGINE OPERATING ON THE OTTO CYCLE AND THE DIESEL PRINCIPLE

proaches the requirements for best efficiency enumerated before than does the constant-volume engine.

COMPARATIVE DIAGRAMS

A comparison of pressure-volume diagrams computed for a 4 by 6-in. engine, Fig. 3, will bring out more clearly the actual differences in the two types of engine. In computing these diagrams the following assumptions were made to make comparison under identical conditions:

(1) Compression pressures—Otto, 108 lb.; Diesel, 500 lb.
(2) Ignition pressure—Otto, 400 lb.; Diesel, 500 lb.
(3) Value of n, 1.35 for both compression curves
(4) Value of n, 1.38 for both expansion curves
(5) That ignition took place instantaneously in the case of the Otto engine and that ignition took place for 15 deg. of crank travel in the Diesel engine, expansion beginning immediately at the end of combustion
(6) That the exhaust valves opened when the piston was ½ in. from the lower dead-center

Aside from the difference in shape of the two diagrams it is well to note the actual difference in total cylinder volume between the two types of engine. The distance from the ignition line to the line marked "clearance

Digitized by Google

line" is the actual volume of burned gas remaining in the combustion chamber, and it is this volume of gas that must be reexpanded before inspiration of the charge can take place. Thus it is instantly seen that the volumetric efficiency which depends directly upon this volume is greater in the case of the Diesel engine. The actual result of this can be seen in Fig. 4. Also, because of this difference in volume, there is less heat loss to the cooling water from the combustion chamber in the Diesel than in the Otto engine.

In the case illustrated the length of the diagram is 6 in., the pressure scale is 100 lb. per in. in height, the area of the Otto diagram is 5.15 sq. in., and the area of the Diesel diagram is 4.94 sq. in. This gives 86 lb. per sq. in. as the mean effective pressure for the Otto and 82 lb. per sq. in. for the Diesel engine, showing that more power is actually developed by the Otto than by the Diesel engine per square inch of piston area. However, as the efficiency of the Diesel is superior to that of the Otto engine, it will develop more horsepower per pound of fuel burned. Again, the rate and method of fuel injection can be altered so as to cause the combustion pressure to be increased considerably over the compression pressure, in which case the area of the diagram and consequently the horsepower developed would be increased beyond that shown by the Otto engine. Thus, we can expect, with proper fuel injection, equal or greater powers compared with the Otto engine of the same bore and stroke.

Another point well worth mentioning again is the difference in pressure at the time the exhaust-valve opens. In the case illustrated the difference is actually 10 lb. This means that more heat has been abstracted from the fuel for actual power purposes and less heat given to the exhaust, with a net result of increased thermal efficiency.

Diesel Method of Injection

In the Diesel engine the fuel is injected into the combustion chamber by compressed air at a pressure ranging from 700 to 1000 lb. per sq. in. To accomplish this it is necessary to provide a fuel pump, a two or three-stage air-compressor, a compressed-air tank and an air-injection tank or bottle. The fuel pump is designed so that it delivers a measured quantity of fuel to the injection valve, the actual amount of fuel being regulated by a

Digitized by Google

FIG. 4—THE RELATION OF THE INSPIRATION PRESSURES TO EACH OTHER AND TO ATMOSPHERIC PRESSURE

governor according to the load on the engine. As the fuel-injection valve is always under the injection air-pressure, it is necessary for this pressure to be overcome before any fuel reaches the valve. Therefore, the fuel pump must be capable of maintaining a pressure of 800 to 1200 lb. per sq. in. upon the fuel during the delivery period. The air-compressor is so designed that cold air at a pressure of 700 to 1000 lb. is delivered to the injection-air tank. This necessitates the use of a cooler between each stage of compression, and one between the last stage and the tank. The use of the tank is for starting purposes.

As the inspiration and compression strokes are common to all types of engines and the method of injection is the main feature under discussion, a detailed description of the injection and combustion period will be of great interest. During the inspiration stroke, a measured quantity of fuel is delivered near the bottom of the fuel injector just above the needle-valve or spray-nozzle. When the needle-valve is opened, the injection air, which in all cases is well above the compression pressure, is forced against the fuel, atomizes it and forces it into the cylinder. One point worthy of note is the fact that the action of the injection air thoroughly atomizes the fuel prior to injection, and upon this atomization depends the combustion efficiency of the cycle. The amount of fuel, as before stated, is regulated by the fuel pump and governor. The duration of injection or combustion is also regulated according to the load on the engine. For light loads the injection valve remains open a shorter period than for heavy loads. Aside from the advantage of thorough atomization there is one great objection to this method of injection, namely, refrigeration during injection. As the compression pressure is about 500 lb. and the injection pressure between 700 and 1000 lb., there will be a very rapid expansion of the injection air from the maximum to the compression pressure. This rapid expansion causes a great reduction in the temperature of the injection air and fuel, just as rapid compres-

Digitized by Google

sion causes an increase in the temperature. The effect of this sudden reduction of temperature causes a time lag in the combustion, because cold fuel is difficult to ignite, as well as the collection of small particles of fuel on the piston, at which point local burning occurs. The result of this is an invariable sag of the piston head due to excessive local temperature. Were it possible to use highly heated air for injection, this refrigeration would to a great extent be overcome. However, with the Diesel method of injection, combustion would take place at the injection valve prior to the injection period. It is well to note that in the Diesel engine the fuel injection is in mechanically timed relation to the piston position, but as the injection and compression pressures are always constant, the rate of injection is also constant, which limits the engine's flexibility.

Summarizing the advantages and disadvantages of the Diesel method of injection, they are as follows:

ADVANTAGES

(1) Fuel injection mechanically timed
(2) Fuel thoroughly atomized prior to injection
(3) Widely different fuels can be used without alteration
(4) Rate of burning controlled mechanically
(5) Two-stroke principle can be used successfully

DISADVANTAGES

(1) Refrigeration during injection.
(2) Reduced flexibility
(3) Use of a high-pressure fuel pump
(4) Use of an air-compressor, coolers and tanks
(5) Troublesome to start

Hvid Method of Injection

In the Hvid engine the fuel is injected into the combustion chamber by a pressure rise in the fuel cup, caused by the explosion of part of the fuel charge, and the operation takes place as follows: During the inspiration stroke of the piston, fuel and air are drawn into the fuel cup through mechanically timed valves, simultaneously with the filling of the cylinder with pure air through the main inlet-valve. On the compression stroke the fuel and air in the cup become heated to such a point that combustion of the lighter or more volatile particles of the fuel takes place. This causes a sudden rise in the pressure within the fuel cup above that in the main combustion chamber, with the result that the fuel is

Digitized by Google

atomized and forced into the highly heated air in the cylinder. The fuel is burned in suspension or directly as it enters the heated air, causing a slight rise in pressure within the cylinder. From this point on the expansion and exhaust strokes are identical with those of any internal-combustion engine.

As in the Diesel engine, the amount of fuel admitted to the cylinder is governed by the load on the engine, but the ignition is not mechanically timed. The control of the time of ignition is entirely by use of proper sized injection holes in the fuel cup for a given compression pressure and fuel. Although this method of timing the ignition proves quite satisfactory over a considerable range of speeds when the fuel and compression remain constant, should there be any variation in the compression pressure or the fuel used, a considerable variation in the time of injection would occur.

It would appear from this that a multiple-cylinder engine would not operate as successfully as a single-cylinder engine, unless the compression pressure were uniform in all cylinders. With this method of fuel injection it is not possible to use the two-stroke cycle principle, because the charging of the fuel cup with air is absolutely necessary to form an explosible mixture. This charging is done during the suction stroke of the piston and would be very difficult to accomplish if inspiration and exhaust occurred simultaneously, as in the two-stroke engine. Thus it is seen that the Hvid principle is limited to the four-stroke principle of operation and, therefore, is limited relative to the weight per horsepower.

Summarizing the advantages and disadvantages of the Hvid method of injection, they are as follows:

ADVANTAGES

(1) No working parts for the injection of the fuel
(2) Fuel thoroughly atomized prior to injection
(3) Fuel heated prior to injection
(4) Flexibility much greater than Diesel
(5) Easily started
(6) Fuel economy greater than Diesel because of heating fuel

DISADVANTAGES

(1) Fuel injection not mechanically timed
(2) Inability to use the two-stroke principle of operation
(3) Necessity of changing fuel cup for widely different fuels

Digitized by Google

McClintock Method of Injection

In the McClintock engine the fuel is injected into the combustion chamber by compressed air trapped in a separate chamber during compression. The operation of this engine is as follows: When the pressure in the cylinder is the least, or during inspiration, fuel, which is under a slight pressure maintained on the fuel tank by a small air pump, is deposited in a small chamber in direct communication with the combustion chamber through small injection tubes. During the compression stroke the air is compressed into a separate chamber through an automatic valve. As the clearance between the head and the piston is only that necessary for mechanical purposes, practically all of the air in the cylinder is compressed into this chamber.

When the piston starts on its power stroke, the air from the chamber is by-passed into the combustion chamber through a mechanically timed valve and a Venturi-shaped port into which project the fuel tubes. Because of the shape of the air port, the fuel is drawn from a small chamber and an intimate mixture of air and fuel takes place, with the result that the combustion begins immediately and with a close resemblance to the Bunsen burner. The amount of fuel as well as the duration of combustion is controlled mechanically by the load on the engine. With this method of burning, extremely high temperatures result, and the materials for the injector and Venturi tubes must be very carefully selected.

From a standpoint of combustion, this engine possesses the advantage of an intimate mixture between the fuel and the air needed for combustion. However, as the piston must move on its down stroke a considerable distance before the transfer of air takes place, combustion comes late in the stroke, with a resultant high exhaust pressure and temperature. The engine is, by the way, just as flexible as most automobile engines.

Summarizing the advantages and disadvantages of the McClintock engine, they are as follows:

ADVANTAGES

(1) Fuel thoroughly atomized and mixed with the air
(2) Fuel heated prior to injection
(3) Flexibility extremely good
(4) Rate of burning can be mechanically controlled
(5) Two-stroke principle can be used successfully
(6) Fuel economy higher than Diesel
(7) Widely different fuels may be used without alteration

Digitized by Google

DISADVANTAGES

(1) Complicated valve mechanism
(2) Fuel injection not mechanically timed
(3) Somewhat troublesome to start—similar to Diesel
(4) Advantage of high compression partially lost prior to combustion

Gernandt Method of Injection

In the Gernandt engine the fuel is injected into the combustion chamber by super-compressing a portion of the products of combustion which have been trapped at the time the pressure in the cylinder has attained its maximum. Mechanically, this can be accomplished in various ways, depending upon the general design of the engine, and the trapping chamber may be actually sealed by the use of valves between the super-compressing means and the combustion chamber, or be in direct communication with the combustion chamber through the very small injection holes. In either case the injection method is identical and takes place as follows:

During the suction stroke in a four-cycle, or during simultaneous exhaust and inspiration in a two-cycle engine, fuel is deposited in a small chamber between the combustion chamber and the super-compressing means, either by gravity or under a slight pressure maintained on the fuel in the tank. The fuel is metered and passes through a mechanically timed valve. During the compression stroke the fuel attains temperature and the pressure rises in the fuel chamber. When the piston reaches its upper dead-center, the products of combustion, previously trapped, are super-compressed mechanically and forced through the fuel chamber and into the combustion chamber.

Thorough atomization takes place during the injection period, as in the Diesel engine, but in this case the injection gas is highly heated and refrigeration has been practically eliminated, the amount of the products of combustion necessary for injection being so small that the burning effect has not been impaired. Also, there is no burning of the fuel until it is actually injected into the combustion chamber. In this engine the fuel, the injection and the rate of injection are mechanically timed, and with an increase in the crankshaft speed there will be a corresponding increase in the rate of fuel injection because the fuel must enter the combustion chamber during a certain angular travel of the crankshaft and

Digitized by Google

not during a certain fixed time. Thus the flexibility of this engine will be very good.

Actual tests on this method of injection have shown promising results, and the speed limitation of a multiple-cylinder engine will depend only upon the combustion rate of the fuel, which, in turn, is dependent upon the thoroughness of atomization, the rate of injection and the shape of the combustion chamber. Experiments are now under way to improve the fuel combustion rate.

Summarizing the advantages and disadvantages in this method of injection, they are as follows:

ADVANTAGES

(1) Fuel injection mechanically timed
(2) Fuel heated prior to injection
(3) Fuel thoroughly atomized prior to and during injection
(4) Rate of burning mechanically controlled
(5) Widely different fuels can be burned without alteration
(6) Fuel economy is greater than Diesel because of preheating
(7) Greater flexibility
(8) Two-cycle principle can be used
(9) Engine very easily started

DISADVANTAGES

(1) Addition of super-compression means, making engine more complicated than the Hvid but much less so than the Diesel

In conclusion, the main point to be brought out is that regardless of the method used for the injection of fuel, advantage should be taken of the high economy and the possibility of burning the heavy fuel oils actually accomplished by the use of the high-compression oil engine.

THE DISCUSSION

QUESTION:—I would like to ask Mr. Gernandt if the principle he mentions is his own idea, and if it could be built into a small, a medium or a high-speed engine.

ANSWER:—Yes, I can answer to both questions. The engine we first used was a 3 by 5-in. single-cylinder. The results we got from this were nothing to boast of, but we built a second engine, a 4 by 6-in. single-cylinder, and it runs very smoothly. It is a stationary engine. The speed ranges from about 200 to 860 r.p.m. and the reciprocating parts weigh from 16 to 18 lb.

Digitized by Google

QUESTION:—Would there be anything to interfere with its use on a multiple-cylinder engine?

ANSWER:—No.

QUESTION:—Could the speed limit be increased if the atomization of the fuel were improved?

ANSWER:—The speed limit depends upon the combustion rate of the fuel. The higher the atomization of the fuel, the better and quicker is the burning. In this way the combustion rate is increased.

QUESTION:—Could it be further increased by having more points of injection?

ANSWER:—The number of injection holes has a great deal to do with it, as the combustion rate depends upon the proper distribution of the fuel. These holes are about No. 56 drill, and there are three. They are so spaced as to permit the quickest union with the air.

QUESTION:—What is the heaviest fuel that has been tried in this type of engine? Has Pennsylvania or asphalt base been used?

ANSWER:—We have not gone into that very deeply. Experimenting is now going on. As a matter of fact we operated on lubricating oil taken from the crankcase of an automobile. It was pretty black. Possibly it was only half fuel. I do not think there is any limit to the heavy fuel one can burn in this engine.

QUESTION:—Could you use this method on a 4 by 6-in. engine, running 1000 ft. per min. piston speed?

ANSWER:—Yes, we are using it on an engine of that size now.

QUESTION:—Is there greater flexibility in the two-cycle than in the four-cycle engine, and a greater amount of power per pound of engine weight?

ANSWER:—Yes, there is. The greater the impulses per cylinder or impulses per minute, the greater the flexibility. Flexibility depends upon the number of impulses as well as upon the weight of the reciprocating parts.

QUESTION:—Would there be any difficulty in scavenging a two-cycle engine?

ANSWER:—No, because in this type of engine the scavenging agent is pure air, not a mixture of fuel and air. In the ordinary type of two-cycle engine using a carbureter the ports must be designed so as to scavenge the exhaust gas perfectly and not lose any of the scavenging

Digitized by Google

mixture. You can lose a lot of air through scavenging and yet not lose much in power.

QUESTION:—Have you made tests to find at what particular position the injection should take place to get the best fuel economy?

ANSWER:—No, we have not.

QUESTION:—The combustion period is short. Is there not some particular way of injecting the fuel to get the highest efficiency?

ANSWER:—Yes, there is. As I have stated, experiments are being conducted to ascertain the best position for the injection holes, their correct size and the proper rate of injection. In injecting heavy oil the fuel must get to the air, and it has to be done rapidly, as quickly as possible. It can be done, however, by a correctly shaped combustion chamber, injecting holes of the proper size and a maximum rate of plunger travel.

QUESTION:—Do you need the same compression pressure as the Diesel engine?

ANSWER:—Yes; about 450 to 500 lb., depending upon the fuel used.

QUESTION:—What is the relative size of the plunger?

ANSWER:—Three-quarters inch diameter by ¼ in. stroke.

QUESTION:—Is the plunger cam-operated?

ANSWER:—Yes. The injection takes place during about 35 deg. of crank travel. In the Diesel engine fuel is injected during about 50 deg. of crank travel. Injection starts at about 8 deg. before dead-center and continues to 38 to 42 deg. past dead-center.

QUESTION:—You regulate the power by regulating the fuel, but such a small amount of fuel is used per stroke that you must have difficulty in controlling the engine at very low speeds.

ANSWER:—The control of the engine is entirely by the amount of fuel burned. The needle-valve regulates the quantity of fuel. We have run as low as 200 r.p.m.

QUESTION:—At high speeds the time limit is short, and the fuel holes are so small that the super-compression space might not be totally filled. Will there be pressure enough for fuel injection?

ANSWER:—Super-compression goes far beyond the compression pressure so that there is always an excess of pressure no matter what the speed of the engine may be. The plunger begins its downward stroke a short time

Digitized by Google

before upper dead-center and continues about 30 deg. past dead-center. In larger engines the super-compression chamber may be sealed with a valve between the combustion chamber and the super-compression means and actually trap the high-pressure gas.

QUESTION:—You claim that the efficiency of the Hvid engine is above that of the Diesel. Will you explain how that can be?

ANSWER:—It is due to the heating of the fuel in the Hvid engine. There is a very rapid explosion in the fuel cup that thoroughly atomizes the fuel. In the Diesel engine the injection air is cooled and they aim to put the fuel into the combustion chamber just ahead of the injection air to reduce the refrigeration action as much as possible. Efficiency really depends upon the degree of atomization.

QUESTION:—In the Diesel there is the onrush of the heavy pressure air whereas the Hvid has only the small injection holes for atomization.

ANSWER:—The Diesel has the same thing. The Diesel mixes air and fuel before the injection and atomizes the fuel during injection through small holes, as in the Hvid.

QUESTION:—Do you think the Hvid engine draws nothing but pure air into the cylinder during the suction stroke? The fuel goes in, and comes out of the holes in the center.

ANSWER:—Some of it does, but the amount is very hard to determine. There is some burnt gas, the same as in the Diesel. Their fuel goes in on the opposite side of the injection holes, and they depend upon the time element and the distance of travel being such that the fuel actually remains in the cup.

QUESTION:—Is there a knock in the Hvid engine?

ANSWER:—I believe there is. The problem with them is the timing of the fuel injection. It is done entirely by the size of the holes in the fuel cup. For certain compressions they have holes of a certain size. If the holes are correctly planned for a compression of say 450 lb. and there should be a drop in compression, the holes would be too small and the fuel would go into the combustion chamber late. If the compression were increased above 450 lb., the holes would be too large and fuel injection too early. It is very difficult to design for variations in compression. It also is difficult to keep the compression balanced in a multiple-cylinder engine, and it is upon

Digitized by Google

this compression balance that the Hvid principle of injection depends. With a hole too large the fuel would enter the cylinder early and it is possible to get a knock. The same thing would happen if a lighter fuel were used. As to the relative atomization of the Diesel and the Hvid engines, the Diesel injection valves are designed so as to present a labyrinth passage for the air and fuel. This insures thorough atomization and better burning in place of refrigeration effects. I do not know that it is due to high burning. It is more of an injection of highly atomized vapor than two or three spurts of flame. You get partially the same effect in breaking up the fuel by an explosion, as in the Hvid, but the injection is that of two or three spurts of flame.

Digitized by Google

MINNEAPOLIS SECTION PAPERS

CARBURETER AIR CLEANERS

By W G Clark[1]

DURING the war the trend of tractor engine design toward increased efficiency resulted in many improvements and discoveries in accessories, not the least of which is the carbureter air-cleaner. The value of air-cleaners is now fully recognized and they are used as standard equipment on the majority of tractors.

Air-cleaners are classified into groups as follows: (*a*) cleaners having cloths or screens, or both, to catch dust; (*b*) inertia cleaners; (*c*) those employing water or some other liquid to trap dirt and (*d*) centrifugal or gravity cleaners.

The first class is practically obsolete; illustrations of two of this type are shown. Inertia cleaners are not widely used, but present possibilities. Liquid cleaners of various designs are in considerable use. The author believes that the slight advantage in efficiency of this type over the better class of dry-type cleaners is not sufficient to compensate for their greater size and difficulty of operation. Many wet-type cleaners are employed because the moisture they impart to the carbureter air is necessary on account of improper kerosene engine design. The operation of different forms of wet-type cleaners is illustrated and described. The centrifugal or gravity-type cleaner is most widely known and used. Its small size, simplicity, efficiency, ease of attachment, and the minimum care necessary for its efficient operation, commend it to the majority of tractor builders. An illustrated description of this type is given.

The trend of engine design in the tractor and the automobile fields during the past few years has been more along the line of increased efficiency of prevailing types than toward the development of new types. This is logical in the development of a mechanism as new as the gas engine, although the demand for higher efficiency has perhaps been hastened and rendered more insistent by the war. This demand was naturally felt first by the accessory people, especially

[1]Engineer, Wilcox-Bennett Carbureter Co., Minneapolis, Minn.

Digitized by Google

the makers of magnetos, carbureters and bearings, and the fact that it was some time before any appreciable progress was apparent showed that too much of the burden had been placed on them. It is gratifying to note that rapid progress has been made since the engine designers have cooperated by taking over their share of the work.

One of the most important factors in improving efficiency and service in automotive work, was the early recognition of the fact that dirt and carbon are the worst enemies of the internal-combustion engine. Changes in design along protective lines and the application of external preventative devices in the form of air cleaners, have done much toward increasing the operating efficiency and life of field engines. I think it is not necessary to discuss the need and value of an air cleaner, especially for tractor and truck engines. Fully 80 per cent of the different tractors and several trucks have air cleaners as standard equipment. The specifications of the United States Army for trucks and tractors include adequate air cleaning devices for the carbureter. The destructive effect on the cylinders of dirt and other incombustible mineral matter is well known. The air cleaner is an important part of the field equipment. Everyone who attended the National Tractor Demonstration at Salina this year will testify that the air cleaners had plenty of work to do. Pictures taken at the time give some idea of the tremendous dust clouds in which the tractors had to work.

Types of Air Cleaners

The earliest form of air cleaner was merely a fine-mesh screen of considerable area attached to the carbureter air-intake. This was used several years ago, but for obvious reasons was not very efficient or satisfactory. Another of the earlier forms of cleaner was called the "rain type," of which the modern air washer or water cleaner is a development. It was a modified form of the washers and humidifiers used for cleaning and moistening air in public buildings. The cleaning was accomplished by drawing the carbureter air through a fine film or sheet of water which flowed over a screen to a reservoir and return. It was very cumbersome and impractical for field use, although if well made it was quite effective.

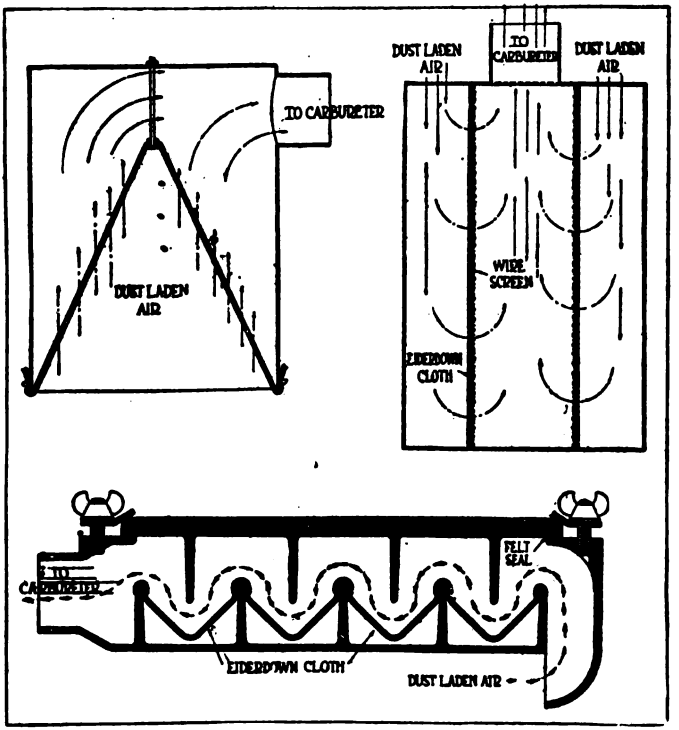
Digitized by Google

There are several types of cleaner now in use on tractors and trucks, namely:

(1) Cleaners having cloths or screens or both to catch the dust
(2) Inertia cleaners
(3) Those in which water or some other liquid is used to wash the air, and
(4) Centrifugal or gravity cleaners

Cloths and Screens

The first type is practically obsolete. It is troublesome, ineffective and bulky, as to clean efficiently the cloth or screen area must be very large to cut down the air velocity and yet provide any considerable capacity.



Figs. 1, 2 and 3—Screen Type Air Cleaners Employing Flannel or Eiderdown Cloth
The Dust-Laden Air Is Drawn Through the Cloth in the Two Upper Ones and in the Lower the Dust Is Collected on the Surface

Digitized by Google

Both cloth and screen soon clog and restrict the flow of air to the carbureter, thus enriching the mixture. This creates carbon and causes overheating and other kindred troubles. There have been numerous forms of this type of cleaner, of which Figs. 1, 2 and 3 are examples.

Fig. 1 shows a cylindrical drum closed at the end connected to the carbureter, and covered at the other end by an eiderdown cloth held in the shape of a cone by a wire at the top. The air is drawn upward through the cone of eiderdown and thence into the carbureter. With this cleaner the operator would have to clean the cloth very frequently in dusty field work or carry considerable cloth with him for the many changes necessary in a day's run.

Fig. 2 illustrates a form in which an eiderdown or flannel cloth is used, but the air is forced to reverse its direction several times in passing around baffle-plates which are intended to direct the dust-laden air into contact with the cloth.

Fig. 3 shows a cleaner having both cloth and screen, the latter serving to hold the cloth in place. No provision is made for taking this cleaner apart.

Inertia Cleaners

The second class I have called inertia cleaners, because their action depends upon the inertia of the dust in the air to carry it out of the air-stream when the air-flow is suddenly reversed or changed before passing to the carbureter. One form of this type of cleaner, of which there are now several varieties, is shown in Fig. 4. It consists of a rectangular metal casing with one side open and a connection from the closed side to the carbureter. The open side of the casing is placed against the outside of the radiator core facing in the direction of air-flow through the radiator, so that the carbureter air is drawn out of the air-stream in the reverse direction. The inertia of the dust being drawn through the radiator is supposed to carry it beyond the open end of the cleaner and through the radiator, not being deflected from its path by the suction of the carbureter. The actual efficiency of this cleaner is rather problematical as it is difficult to catch and measure the dust in any way. Practically the only way to test it is

Digitized by Google

to try it on an engine in the field and judge of its efficiency by the condition of the cylinders.

A somewhat similar form of inertia cleaner is placed behind the fan instead of in front of the radiator, so that the air is forced through the cleaner instead of being drawn through. Its efficiency is dependent upon the maintenance of a certain air velocity for a given proportioning of the cleaner openings; a variation of fan speed interferes seriously with its effectiveness. I have no available data on these forms of inertia cleaners. There must be a considerable volumetric loss with their use, due to the fact that the carbureter air is drawn in a reverse direction from that of the fan airstream, which possesses the kinetic energy and inertia of its velocity and direction of flow.

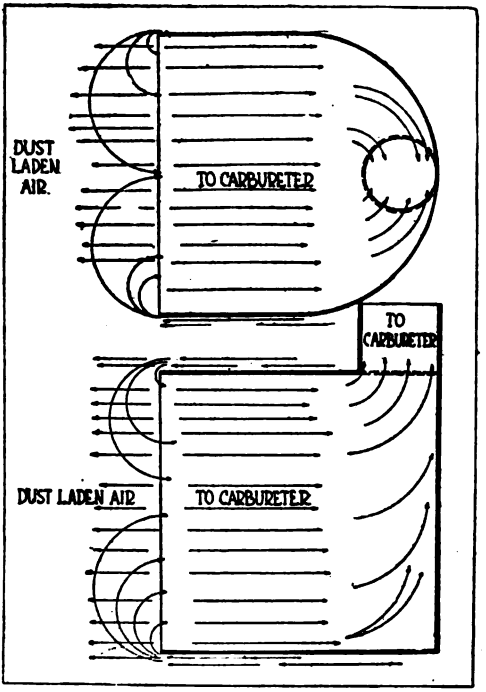


FIG. 4—THE PRINCIPLE OF OPERATION OF THIS INERTIA AIR CLEANER IS THAT THE AIR PARTICLES ARE ENTRAINED BY THE SUCTION OF AIR THROUGH THE RADIATOR

Digitized by Google

Liquid Traps

The third type comprises those cleaners or washers in which a liquid such as water or kerosene is employed to trap the dust. The demand for an air-washer or wet-type cleaner was created primarily by engine operators and owners of tractors in exceptionally dusty territories, who felt that other types of cleaners were not efficient enough for adequate engine protection. However, judging from data on most of the best air-washers and dry-type cleaners, I do not believe that the slight advantage of the wet type over the best dry types is sufficient to compensate for the extra trouble and difficulty encountered in the use and care of a wet-type cleaner. The best dry-type cleaners will catch from 95 to 100 per cent of the dust passing into them, the efficiency varying with the fineness, weight and volume of the dust. Under the most adverse conditions for the dry type, the best air washers will show not more than 2 or 3 per cent better efficiency. Such conditions are most frequently encountered in some of our Western States, where the dust is largely composed of volcanic ash—lava dust. This dust is very light and fine, which makes it hard to stop. It also contains considerable vegetable matter, so that of the small percentage that escapes the dry-type cleaner, the major portion is combustible vegetable matter that will burn in the cylinders without deposit.

I think that many have been misled as to the efficiency of the air-washer by comparing it with building air-washers and humidifiers. While their action is somewhat similar, they differ in a very important respect. The ordinary building air-washer deals with air at low velocities through which finely divided water particles are passed. The carbureter air-washer deals with air at high velocities which must be pulled through a quantity of water. In one case the surface of a large number of water particles comes in contact with a slowly moving volume of air, affording ample time, when properly designed, to wash all the air thoroughly. In the other case a volume of air is forced through water at high speed. This forms air bubbles which trap within themselves particles of dust. These never get into contact with the water and are carried through into the carbureter. The best carbureter air-washers are those in which these air bubbles are broken up and reduced to

Digitized by Google

a minimum. Their presence accounts for the fact that even the best air-washers are not always 100 per cent efficient, especially under the extreme conditions mentioned. I know of two carbureter air-washers that are not as efficient as some dry-type cleaners because of this defect. Under ordinary field conditions the dif-

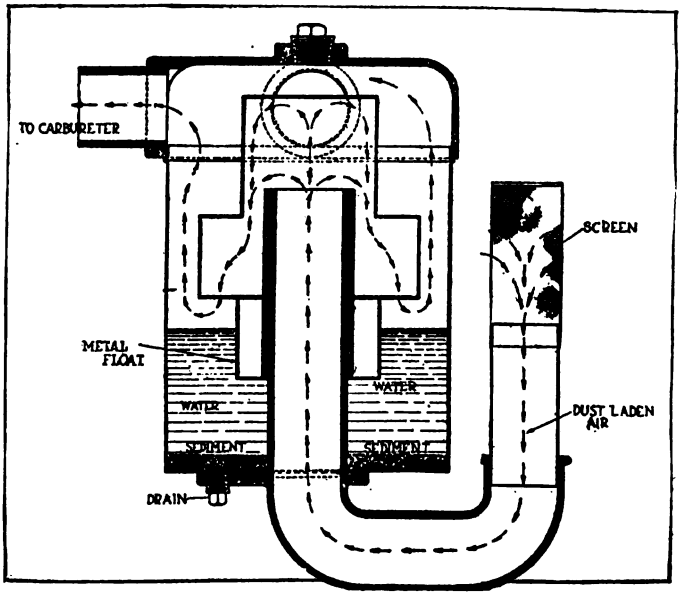


FIG. 5—IN THIS TYPE OF LIQUID AIR CLEANER THE AIR AND THE DUST PARTICLES STRIKE THE WATER BEFORE ENTERING THE CARBURETER

ference in efficiency between the wet and dry-type cleaners is very slight. I think that if the truth were known most tractor owners now using the wet-type cleaner do so on account of the moisture which these furnish to the intake air, rather than because of any really better operation. For some engines which do not cool any too well, especially when using kerosene, the heavily moistened and cool air from a water cleaner is almost as much a necessity as freedom from dust.

This heavy moisture content which some air-washers impart causes a large water consumption, the amount varying with the temperature. One well-known air-

Digitized by Google

washer is said to use up 30 quarts of water in a day's work, under ordinary summer temperatures. All air-washers are not as bad as that, but it is both troublesome and inconvenient to refill them twice a day. This fact and their susceptibility to freezing in cold weather form two of the main objections to an air-washer.

Figs. 5 and 6 are two forms of air-washer now in use. The first has an additional objection to those already mentioned, in that it employs a floating member with a large bearing surface exposed to the wearing action of the dust entering the cleaner. These surfaces are in the direct path of the dust, which must effect some wear if not actual clogging of the bearing.

Fig. 6 is a water cleaner brought out over a year ago to satisfy certain demands for a wet-type cleaner. It embodies several novel features designed to eliminate so far as possible some of the objectionable properties of the wet-type cleaner. It consists essentially of a centrifugal air-cleaner suspended within a cylindrical casing containing a quantity of water. This water is made to revolve within the container by the whirling action of the air drawn into it by the suction of the carbureter. The water rotates because the air is drawn into it tangentially through two spiral tubes in the inner circumference of the casing. The dust-laden air enters as shown and passes into the water compartment through openings in the spirals at *A*. The rapidly whirling air causes the whole mass of water to revolve so that it piles up against the sides in approximately the position shown by the dotted line. This completely submerges the lower ends of the spirals in a heavy spray, so that all the air must pass through the water spray before escaping upward into the openings *C* of the inner air cleaner.

The air-cleaner has three spirals on its inner circumference through which the air and entrained moisture pass. The centrifugal action set up in the inner cleaner breaks up any air bubbles, completes the cleaning of the air and also throws down any drops of water that may have been picked up in the air. These water drops are thrown downward and back into the water container through the open end of tube *B*. This reduces the humidity of the washed air and also prevents excessive water consumption. The clean air after passing out of the spirals in the inner cleaner escapes upward and out through the elbow at top to the carbureter air-intake.

Digitized by Google

As long as there is any water in the container the whirling of this keeps the end of tube *B*, which is very close to the bottom of the container, sufficiently open for the water thrown down to re-enter the reservoir. However, if the water supply is allowed to evaporate entirely, enough mud and dirt will settle under the open end of *B*

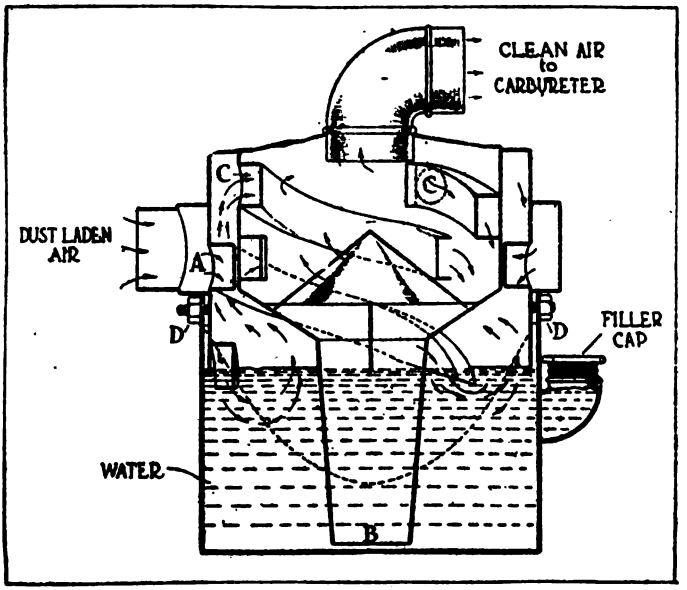


FIG. 6—WATER WHIRLING RAPIDLY THROUGH SPIRAL PASSAGES IN THE LOWER COMPARTMENT IS RELIED UPON TO CLEANSE THE AIR

to seal it, so that even if the container should run dry, the inner air-cleaner will collect the dust as a dry-air cleaner. Of course, if the water container is dry and also clean, no such cleaning action is possible unless opening *B* is closed. Under normal summer temperatures one filling of water should last a full days' run of a tractor in the field.

The reservoir holds about 1 gal., which is a very low water consumption in comparison with others. The air contains so little moisture that it does not interfere with the carbureter action on gasoline, as is the case with some

Digitized by Google

other water cleaners. The whirling action of the water in the reservoir creates a heavy spray over the openings of the spirals so that all the air must pass through the water spray instead of bubbling through a volume of water. This practically eliminates the formation of bubbles, thereby increasing efficiency. Furthermore, any particles of water containing dust are thrown out of the air while passing through the inner cleaner and drop back into the water reservoir again. This also accounts for the low water consumption. Except at the instant of starting, the frictional resistance of this water cleaner is no greater than that of an equivalent one of the dry type, because when once started it requires but little force to keep the body of water revolving.

Centrifugal-Type Cleaners

The fourth type of cleaner and the most widely used works on the centrifugal or gravity principle. Figs. 7 and 8 are examples of this type. Fig. 8 shows a centrifugal or gravity cleaner that is used on a large percentage of the makes of tractor which use air-cleaners. The air is drawn by suction through openings in the sides of the cleaner into the spiral tubes. These spiral tubes have a downward pitch which gives the dust-laden air a whirl, so that centrifugal action and gravity throw the dust out of the air under the cone and into the container below, while the clean air passes upward through the top and into the carbureter.

Fig. 8 is a centrifugal cleaner of the same type, differing only in outward appearance and size. The principle and action are identical and the construction nearly so.

There are several other forms of the four types of cleaner, but the ones shown and described are representative and serve to illustrate the principles and design involved.

THE DISCUSSION

A. W. Scarratt:—Do you really think that the dirt thrown down in the cleaner will be solid enough to make an airtight seal?

Mr. Clark:—It becomes solid as the water evaporates.

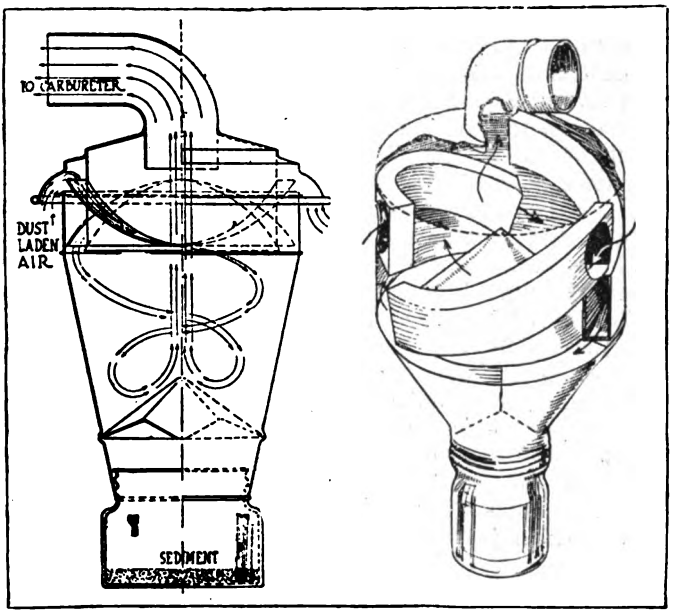
Mr. Scarratt:—Will it be airtight?

Mr. Clark:—It will, if you get any considerable quantity of it. The bottom of the tube is about 1/16 in. from the bottom of the container, and if ¼ in. of dust collects

Digitized by Google

there it becomes airtight. Of course, if the reservoir is clean and empty at the same time, you get no cleaning effect from the water, but if there is dust there and the water does evaporate, the farmer still has a cleaner.

R. B. SHOOP:—How much of a deposit will there be on the bottom at the end of a 10-hr. run when operating in heavily laden air?



FIGS. 7 AND 8—CENTRIFUGAL FORCE REMOVES THE DUST PARTICLES IN THESE TWO TYPES OF AIR CLEANER AND COLLECTS THEM IN A CONTAINER AT THE BOTTOM

MR. CLARK:—Judging from what the dry cleaners will catch under the worst conditions, about a pint in five hours. That is the worst I have ever had reported to me. I was out on an experimental job west of St. Louis recently where we had as bad conditions as any I ever saw. We emptied the air cleaner and got approximately 1 in. of dust for every half-mile round.

A MEMBER:—Must the engine be stopped to remove the glass to clean it?

MR. CLARK:—It is better to do so.

Digitized by Google

Effect of Dust on Engine

A Member:—Has any accurate test been made to determine what damage dust causes when going through an engine of that kind?

Mr. Clark:—I have some pistons at the office which are sufficient evidence on that point. The rings at the top and the ring grooves are worn deepest at the top and the injury is less at the bottom of the piston. Some of the rings are cut into and worn bevel-edged. A representative of one of the prominent piston companies told us that this was impossible. We sent them the pistons to prove our point. If you have any doubt as to the destructiveness of dust take a tractor to the Western coast, or one of the Western States, like Idaho. There are some places in the West where a tractor cannot run for 2 hr. without clogging. Tractors have been known to quit cold on account of the clogging of the lubricating oil-holes, thus cutting out the bearings. There have been cases where the bearings were scooped out.

Chairman Mowry:—I have seen the pistons to which Mr. Clark referred. The lead of an ordinary pencil, after sharpening it in the usual way, could easily be laid in beside the piston under the upper piston ring. The next one was a little less worn; the third still less; the fourth one a little looser than it should have been. The pistons had been run about four weeks.

Mr. Clark:—There was a thick deposit of dirt on the rings, which just about proves the case.

Decrease of Power

Mr. Haggerty:—What is the effect of the air cleaner on the power?

Mr. Clark:—In tests made on engines equipped with them, the loss of horsepower was so small we could not measure it. An engine developing 40 hp. would give a power loss of a little less than 1/40 hp. Of course, there is a slight restriction of the air. If the carbureter is adjusted to the change in air velocity, power loss cannot be detected.

Mr. Haggerty:—Is that true of the water cleaners?

Mr. Clark:—We have been able to detect very little difference between our water cleaners and the air cleaners. Very little power is required to keep the water revolving.

Digitized by Google

MR. HAGGERTY:—I have heard several manufacturers protest against the amount of power lost with the water cleaners.

MR. CLARK:—I have not tested any of the makes other than ours as to friction.

INSTALLATION

MR. SCARRATT:—Are there any points regarding the installation of the air cleaner that it would be to our advantage to know?

MR. CLARK:—The object in installing an air cleaner is to get one with the greatest efficiency and the fewest drawbacks. One of the drawbacks is loss of power. The farther the cleaner is placed away from the carbureter the more power is lost, no matter what system is used. Flexible steel tubing is one of the best means of clogging a cleaner. It figures about 1 hp. lost for every 4 ft. If the carbureter and air cleaner must be connected with steel tubing, the closer they are and the straighter the tube the better. The cleaner should be supported from its body, not hung from the top. Most cleaners are made of sheet metal because of its light weight. Hang the cleaner on the engine and not the engine on the cleaner.

MR. SCARRATT:—Have you made any tests on the flexible metal tubing to determine how nearly airtight it is?

MR. CLARK:—No. I have been assured by makers that with packing in the joints it is airtight.

MR. DONALDSON:—I have heard that an air cleaner should not be placed in front of the breather or opposite the flywheel because the oily vapor it gets will mix with the dust and clog it.

MR. CLARK:—That is true.

A MEMBER:—Mr. Clark has stated that in very hot weather the water cleaner tends to cool the engine. When some water cleaners are used in cold weather the engine cools too much and after a while it will not run at all, so I think the combined air and water cleaner is an improvement over the water type because even with the water let out there is still a cleaner. Otherwise it would be necessary to disconnect the carbureter from the cleaner.

G. C. ANDREWS:—We formerly made a number of oil separators to take oil out of steam. Why not use the principle of these to keep dust out of tractor engines?

Digitized by Google

MR. CLARK:—That could be done, but the volume or area you would have to use would be too great. The cleaner would no longer be an accessory.

CHAIRMAN MOWRY:—That is one of the chief points. The air cleaner must be small enough to fit in close to the engine and not be in the way of anything else. On one tractor the air cleaner is installed in such a way that to run on the belt the cleaner must come off.

MR. SCARRATT:—And that is when it is needed most.

A MEMBER:—How fast does the water revolve?

CHAIRMAN MOWRY:—That is one of the chief points. velocity of the incoming air?

MR. CLARK:—That would be rather hard to measure. We do not aim at an air velocity greater than 4500 ft. per min. Whether the water attains that speed I do not know.

RADIATOR COOLING FANS

By George W Hoyt[1]

IN the cooling system for an automobile engine, the water-jacket must be designed to give ample capacity and free flow of the water. It is essential that water-pump capacities and speeds be figured to equal the radiator capacity so as not to retard the flow of water through the radiator and cause hot water to back up into the cylinder; the radiator must always be kept full and still handle the water as fast as the pump carries it. Fan locations are necessarily considered with relation to the radiator and radiator shroud. Fan diameters, blade path and fan speeds should be given thought, in order that the proper volume of air can be handled to carry heat from the engine. The frontal area of the radiator core in square feet per horsepower developed by the engine and several other details which can be worked out by the fan and radiator manufacturers should receive attention.

The best possible fan bearings must be used, giving special attention to radial and thrust loads, fan speeds, etc. Attention should be given to the method of oiling fan bearings, whether of ball, plain or roller type; the hub should be kept tight and free from dust. Strong fan mountings or brackets are desirable to minimize

[1]Chief engineer, Oakes Co., Indianapolis, Ind.

Digitized by Google

vibration which is always detrimental to all fan parts. In other words, instead of using what space is left on the chassis for fan purposes, far better results will be gained if the foregoing items are given proper attention, thus dissipating the heat produced by the engine in a satisfactory manner. All necessary information on this subject is at present available through the co-operation of car and accessory manufacturers.

The several units which go to make up the cooling system on tractors, trucks and passenger cars are the water-jacket, the pump, the radiator and the fan. There are important points in connection with water-jacket design, such as length and size of jacket, shape of compression chamber, wall thicknesses, etc., and special attention should be given to all of these to insure correct water capacity and also free flow of the water, at the same time making the necessary arrangements to prevent steam pockets.

A pump will throw just so much water. If the pump throws water into the radiator faster than the latter can handle it, the water will bank up through the tank into the cylinder and be held there until it heats. If the radiator is too large, steam pockets will form, hold the steam and cause overheating. If the outfit is designed properly the pump and the radiator will be of equal capacity. The pump must be designed to carry the water at such a speed that the radiator can be kept full at all times and still not have any hot water banked in the upper tank of the radiator, causing it to come back into the cylinders. It has been good practice in the past, as stated by Arthur Modine in his paper on Principles of Tractor Engine Cooling,[2] that for engines up to 50 hp. a good average amount of water to handle is 0.8 gal. per hp. per min. This works out very well. There is one type of cooling system, known as the thermosyphon cooling system, in which a water-pump is not used. The water capacity and the water passages are such as to allow free circulation of the water. It is also necessary to have a good water head in the radiator and above the cylinders, as the circulation depends entirely upon the hot water going to the highest point.

The radiator is of equal importance with all other units in connection with the cooling system. It has been proved that if we get an approximate frontal area of from 0.08

[2]See S. A. E. Transactions, vol. 13, part 1.

Digitized by Google

to 0.10 sq. ft. per hp., we can be certain of satisfactory results so far as the radiator is concerned. This area depends, of course, somewhat upon the type of core, which must have a good free air-flow, and also in part upon the thickness of the core. However, the specification given will apply for average conditions.

Fans

The fan, of course, plays an important part in the balance of a cooling system. There are many different installations on various makes of trucks, tractors and passenger cars throughout the country, but none the less there is always one way of doing a thing that is more nearly correct than any other. Among the engineers there is great uncertainty as to just what type, size and speed of fan should be used for different engines. This depends largely upon where the fan is to be used, on passenger car, truck, tractor or small lighting outfit. If used on a tractor, special attention should be given to keeping the fan bearings free from dust and grit by the use of good oil-tight construction, and this oil-tight feature should be adjustable. For the fans used on passenger cars or trucks, it is not so important to have this adjustable feature on the belt, although it is very good practice to get it if possible. Most engineers will agree that the fan is given about as little attention as any part of the engine, until trouble with heating begins. However, much improvement can be noted in the recent designs. It is found that by selecting a fan of proper diameter and speed to work in connection with other units, such as the radiator and pump, we get far better results. If this is not carefully looked into, we may have a fan running too slow or too fast, and the latter would cause fan noises. The fan may be too small also. These few points are merely mentioned to make clear the factors entering into the design of a cooling system.

It is best practice to use the largest fan that it is possible to get in back of the radiator, clearing all connections by at least ½ in. It should be installed so that the outside diameter of the fan will not overlap the upper or lower tank, and thus pull against a flat, closed surface. After the diameter of the fan has been determined the projected area or blade path must be studied, as this, in connection with the diameter and speed of the fan, determines the number of cubic feet of air handled. It is good practice to make the width of projected area any-

Digitized by Google

where from 1½ to 2¼ in., depending entirely upon the size of the engine to be cooled. It is sometimes impossible to get a fan of large diameter back of the radiator, and in this case the thing to do is to use a blade path as large as possible and still clear the fan belt by ⅜ in. We figure that this distance is entirely satisfactory for most commercial purposes, as the belt must be kept fairly tight or it will not drive the fan.

In case you wish to carry a certain volume of air, say that of an 18-in. fan running at 1800 r.p.m. with a 1½-in. width of projected area, and cannot get a fan of that size into the space back of the radiator, you can select a smaller fan with a larger projected area, giving the same volume of air and running at the same speed from the figures given on the curve charts for fans of different sizes, and step down to that. In other words, it is possible to cut down the diameter of a fan, increase the size of the projected area and still carry the required volume of air at a given speed. Bear in mind that fans of large diameter and slow speed should be used where this is possible. That is just our way of avoiding a large-diameter fan, since all radiators will not accommodate them. You can cut down the size of a fan, increase the blade path, and still get good results.

Size of Fan Pulleys and Belts

After we have properly determined the diameter and width of a fan blade, the width and diameter of the fan pulley must be figured. For fans up to 16 and 18 in. diameter, we have found by experiment that a belt 1¼ in. wide works very satisfactorily where there is no other unit driven by it but the fan. Where the generator is driven by the same belt, the latter must, of course, be wider and heavier. Fan diameters larger than those mentioned take belt widths up to 2½ in. While this is a large belt width, I mention it because we are furnishing it to some manufacturers.

The width of the belt depends upon whether the fan is driven from the flywheel or from a small driving pulley, and whether the speed is 2500 or 1600 r.p.m. Where the pulleys are small in diameter and run at fairly high speeds, a wide belt is needed to prevent slippage. Sometimes it is not possible to get a large degree of belt contact on the pulley. This condition calls for a wide belt, and after a car has been on the road for several months, subject to weather conditions, water, oil and heat, a lit-

Digitized by Google

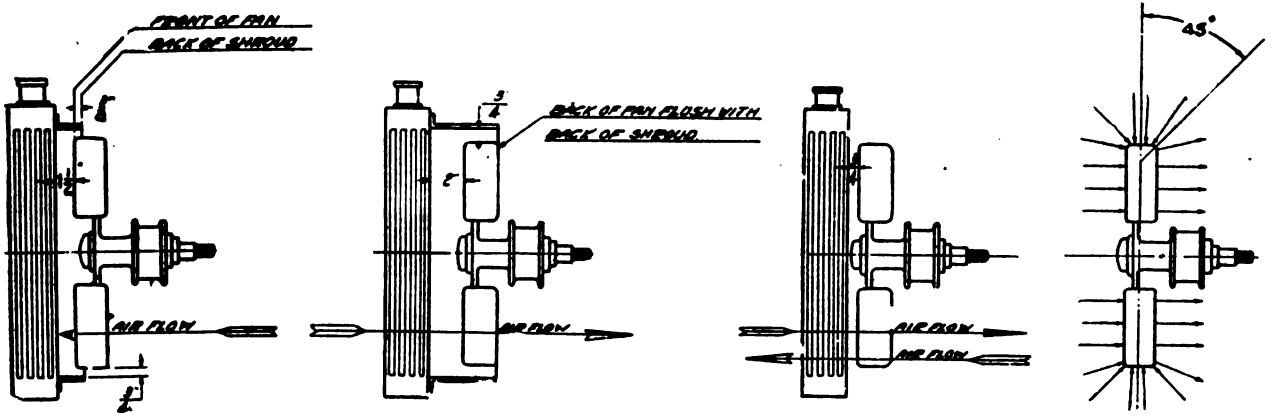
tle money spent on belt width which goes to keep the fan running and helps to keep the engine cool, is well expended. There is some choice between a crown-face and a flat-face pulley. It can be said that this depends somewhat upon the width of belt. If it is possible to use a wide belt, the flat pulley will work very well, and this is true of the belt widths thus far mentioned. However, the tests we have run show that a crown-face pulley is a little the better because it tends to keep the belt centered on the pulley, thereby getting the benefit of the full width of the belt. In cases where the driven and driving pulleys are not absolutely lined up with each other, the edge of the belt tends to ride on the flange of the pulley and decreases its efficiency at that point.

For the final decision on belt widths the material must be considered. Some materials stretch more than others and cause slippage. Wide belts help to overcome this trouble. No matter how efficient the fan may be, if the belt is not large enough to do away with all the slippage possible, the fan will be more or less of a failure for cooling purposes. If the belt is of proper width and the fan diameters are selected as has been suggested, the fan proposition is pretty well taken care of to this point.

We have now practically determined the diameter and length of the fan, and it becomes necessary to settle the diameter of the fan pulley. Before this can be decided, it is necessary to know the approximate amount of air to be carried, and from past tests in the laboratory and the tests of radiator manufacturers we have found that for engines up to 50 hp. there should be an air velocity through the radiator of from 1500 to 1800 ft. per min. This depends, of course, upon the size of engine to be cooled. The smallest pulley used should not be less than 2½-in. diameter, where it is at all possible to install this and not interfere with any other part of the engine. Pulleys smaller than this, as I have said, are very likely to allow belt slippage and decrease fan speed considerably. The fan speed will, of course, vary with its size and the amount of air to be carried, but in general a large fan running at slow speed is more efficient.

The fan proposition then can be stated briefly. The fan pulley must be of such a diameter that in connection with the diameter and speed of the fan driving pulley the fan will rotate fast enough to carry the required volume of air, and the driving pulley must be

Digitized by Google



VARIOUS LOCATIONS OF COOLING FANS WITH RELATION TO RADIATOR AND SHROUD

Blowing Air with Shroud

Drawing Air with Shroud

Blowing or Drawing Air, No Shroud

Curved Four-Blade Fa...

Digitized by Google

large enough to allow a fan pulley diameter of at least 2½ in.

Fan Locations

Some manufacturers use a fan shroud on their car radiators; others do not. The location of the fan depends upon its use. Without a shroud, the fan should be placed with the front edge of the blades ¾ in. from the back of the radiator core. This is done so that there will be as little lost effort in drawing air through all sections of the radiator as when a fan is more than ¾ in. from the radiator. The fan will pull the air from the top and sides of the hood instead of through the corners of the radiator. This distance is also great enough to insure quiet operation and to allow for regular shop variations without interference with the radiator. The location just explained is satisfactory for blowing air as well as drawing air through the radiator, when not using a fan shroud.

When using a shroud and drawing air through the radiator, the front edge of the fan blades should be 2 in. away from the back of the radiator core, and the shroud should be designed so that its back edge will come flush with the back edge of the fan blades, with about ¾-in. clearance between shroud and fan. While that clearance is shown on each side, it would be necessary for belt tension and tightening to make it possibly ¾ in. on one side and a little more on the other side, to permit adjustment of the belt. If a fan is set closer than 2 in. to the radiator when using a shroud, it becomes as noisy as when operating in a shallow pocket. The air has no chance to spread and take a free course through the fan. We find from tests that a fan placed with a 2-in. clearance will give very good results. It has more room in which to draw air through the corners of the radiator and is fairly quiet. The shroud, however, is not the sole reason for the increased efficiency.

There should be a number of louvers of proper size in the sides of the hood to permit the warm air to escape. Attention should be given also to the location of the floorboards or anything that would tend to increase resistance against the fan. All these different pieces should be designed and placed in such a way as to allow the free flow and escape of warm air under the hood.

There is on other point to consider in the design of the fan shroud on a radiator. The shroud should be as

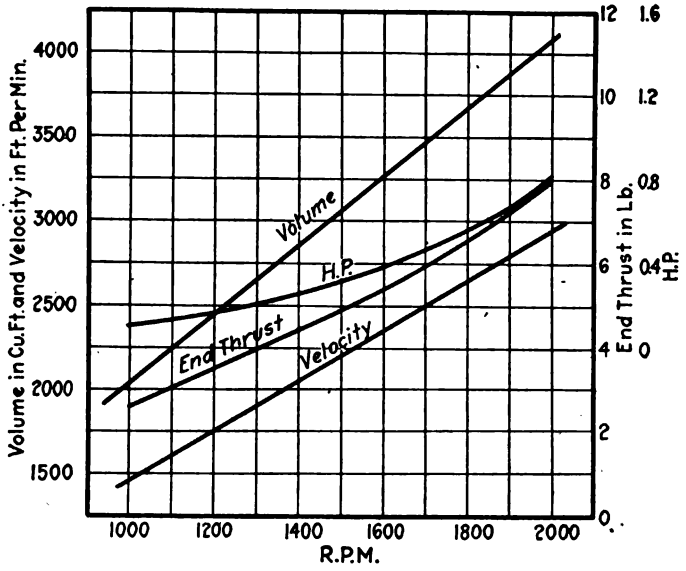
Digitized by Google

free as possible from angles, as these bank the air and hold it in. When a shroud overlaps the back of the fan blades, it will not allow the air to get away from the fan and even forces it back through the corners of the radiator. A fan is often placed with relation to the shroud so that half of the blade width will extend into the shroud and half back of the shroud. With this location air is drawn in all around the end of the blade, and one-half of the blade draws warm air from the engine under the hood and tends to keep this air circling around the end of the blade and decrease the amount of air handled.

There are other locations of a cooling fan such as placing it in front of the radiator when the radiator is in front of the engine. In this case the air should be blown through the radiator and at the same time carry away the hot air of the engine as if it were drawn through the radiator. With the fan in this position the hot air would be pulled through the radiator and have a tendency to warm the water instead of to cool it. There is, moreover, the objection to placing a fan in front of the radiator, that if both are not properly protected, the fan draws in dirt and weeds from the field and is likely to fill the radiator to such an extent as to decrease the chance of cooling the engine. When a fan is used in front of the radiator and a shroud is not employed, the fan is best located to force all the air possible through the radiator. If it is necessary to use a shroud with the fan in front of the radiator, we have found it to be very good practice to locate the fan as shown at the left of the drawing on page 763. This location has proved to be best, as the fan draws in air all around the end of the blade, being located with the front edge ⅜ in. inside of the shroud to keep from spreading the air outside the shroud, and at the same time leave the largest part of the blade out in the open air, drawing in the maximum amount of air it can handle. By placing the fan in this case 1½ in. back from the radiator, enough space is allowed between fan and radiator to spread the air so that it will pass through the corners of the radiator as well as the center. Bear in mind that we allow the fan to project outside of the shroud for the simple reason that it is not under the hood. If it were under the hood we would put it entirely inside and it would then draw the hot air as already explained. We want to place it far enough back to draw in the cool air.

For tractor purposes, I suggest the use of a fan

Digitized by Google



CURVES FOR A 16-IN. FAN

shroud, since the maximum amount of cooling capacity is needed and this secures a gain of about 10 per cent, due to the fact that air can be drawn through the extreme corners as well as any other section of the radiator. If, however, a fan shroud is not well designed as to shape, length and diameter, it can do more harm than good.

In considering which way or in what direction air should flow through the radiator, it is well to bear in mind that we must avoid drawing hot air off the engine, as this will decrease efficiency. For a radiator placed beside the engine the fan location should be the same as when it is in front. There is one more location for a radiator, and that is back of the engine and at the dash. In most cases it is necessary to place the fan back of the radiator and drive it from the flywheel or propeller-shaft. The real objection to this location is that in most designs it backs up so close to the floor-boards that it is impossible to get maximum efficiency from the fan. However, the direction of air flow should be such that warm air will not pass through the radiator from the engine.

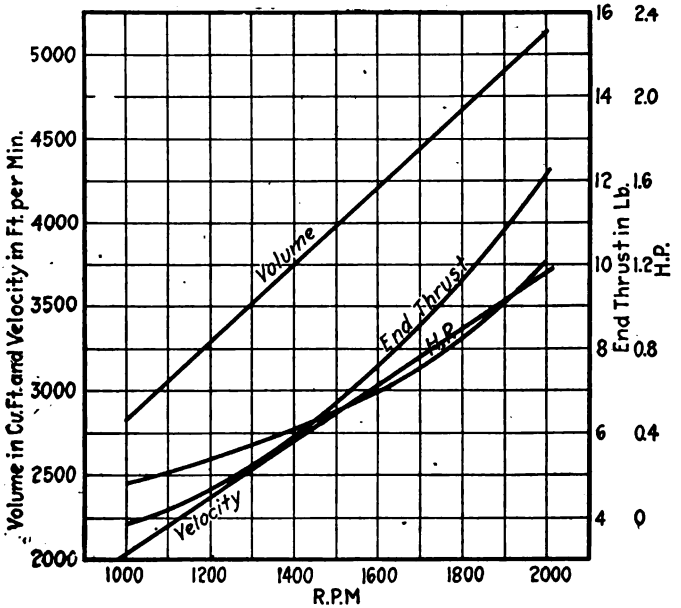
There is one point that I want to make clear with reference to the volume charts. Tests were made with a pitot tube and manometers, using gasoline in the latter.

Digitized by Google

Static pressures as well as the velocity pressures were taken into consideration in reading the height of the gasoline column. The fans were driven by a 5-hp. engine and were tested in an air tunnel 15 ft. long, tapered down to 16 in. in diameter. At the same time the volume test was made. We are also equipped to determine the end-thrust of the fan and the horsepower consumed in driving it. The pitot-tube test is considered the most accurate for determining velocities of air handled by fans, and these should not in any case be compared with values secured by the use of the anemometer, as the latter are approximate only for velocities as low as 1000 to 1500 ft. per min. and these velocities can be obtained by the average-size fan at speeds as low as 800 to 1000 r.p.m

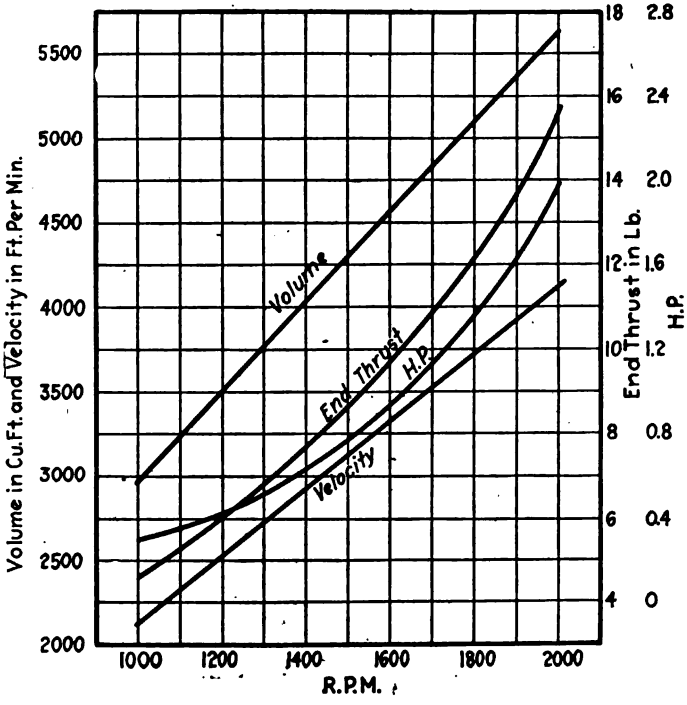
Fan Bearings

The first thing to consider before selecting the type of bearing to be adopted is the load it will have to stand. The radial load on a fan bearing is the weight of the hub, blades, spider and all parts that will revolve on these



Curves for an 18-In. Fan

Digitized by Google



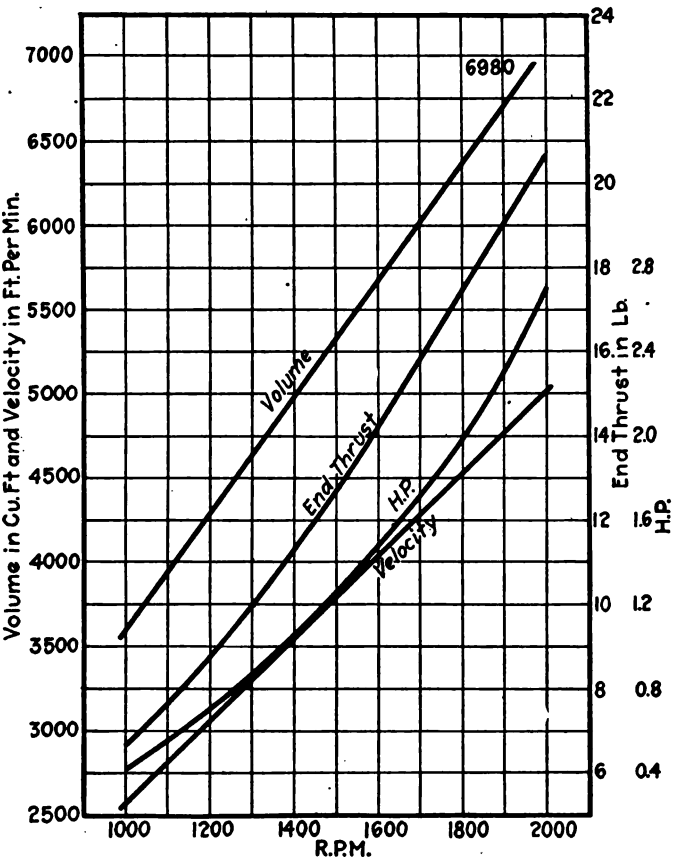
CURVES FOR A 20-IN. FAN

bearings, plus the weight caused by the tightening of the fan belt to secure a drive without slippage. In addition to this there is another load which is a very important factor. It is a well-known fact that the work of a fan is to draw or blow the air through the radiator and get rid of this air properly so that it will not bank up and decrease the fan efficiency. In doing this work a large percentage of the load on the fan bearing becomes end-thrust. In the past there seems to have been a certain difference of opinion among engineers as to the amount of end-thrust caused by carrying different volumes of air. There are three points which must always be considered in determining this, fan diameter, the projected area, or blade path, and the speed of the fan. An 18-in. fan with a 1½-in. projected area, running at 2000 r.p.m. will produce an end-thrust much less in amount than the same fan with a 2¼-in. projected area

Digitized by Google

running at the same speed. A fan running in the open air unrestricted will produce a certain amount of end-thrust, but when placed back of a radiator, between it and the dash and under a hood, this thrust is increased about 25 per cent. The amount of increase depends, of course, upon the amount of restriction of the air. The air will flow through some radiators more easily than through others; some engine hoods have better air outlets than others, which tends to vary the thrust.

A straight roller bearing, if used with a hardened and ground outer sleeve and spindle, will make a very satisfactory bearing for taking care of the radial load, but



CURVES FOR A 22-IN. FAN

Digitized by Google

some special arrangement must be made to take care of end-thrust, the amount of which is such that it should have a ball bearing. A 22-in. fan with 2¼-in. projected area running at 2000 r.p.m. and carrying a volume of air of 6890 cu. ft. per min., will produce an end-thrust of about 20 lb. carrying this through a 16-in. tunnel.

About one out of every ten people who own and drive cars ever oils the fans, but if a plain washer thrust-bearing does not get oil it soon becomes loose and noisy. A ball thrust-bearing of course wears out in time, but there is no doubt that there is less friction in it than in the plain bearing. Engineers who have had experience with end-thrust bearings will agree that the ball end-thrust makes much the higher grade construction. The amount of end-thrust can be found in the curves.

The proper size of annular ball bearing for fan purposes will give satisfactory results and carry both radial and end-thrust loads, but it must be kept properly oiled.

The cup and cone type bearing is by far the most popular, about 75 per cent of the fans used today being equipped with it, which is proof of its efficiency. It is adjustable for both radial load and end-thrust. Properly made and adjusted it will run longer under the abuse that a fan gets than any other type of fan bearing, with the possible exception of an annular one. These two bearings are very much alike, as far as carrying load is concerned, except that one is adjustable and the other is not. It is possible that the cup and cone bearing needs a rather delicate adjustment to work properly and be a life-long proposition, but this is true of any adjustable bearing. Plain washers must not be clamped too tightly or they will score and bind; if they are too loose they will rattle; hence special attention should be given in both cases.

The essential for long-life fan bearings is to make the hub as tight as possible so that the oil can be kept in and the dust out. To accomplish this, the hub must be designed to hold a good amount of oil or grease and the felt washer retainers adjustable. A felt washer that has no adjustment will in time wear large around the shaft and become oil-soaked to such an extent that it gets soft and worse than no washer at all. If we have an adjustment, the felt can be kept tight to the shaft and the oil kept out of the felt, thereby getting a much tighter fan hub. We put adjustable felt washer retainers on the differential carriers of a rear axle, or on front wheel and

Digitized by Google

transmission bearings to keep the washers tight; and this is needed also on the fan hub, which, bear in mind, has the highest speed of any part of the engine.

Conclusions

I hope I have made clear the points to which special attention should be given in laying out a cooling system, and the reasons for these. No one unit can do all the engine cooling; all units must be designed and adapted to each other. I suggest that manufacturers of motor vehicles cooperate with the accessory mnufacturers to such an extent that the latter can help to solve mechanical difficulties, since there is no particular fan or pump or radiator that will meet all the different conditions, and thereby give the maximum amount of efficiency.

THE DISCUSSION

A Member:—Is there any particular advantage in making the contour of the fan an arc?

Mr. Hoyt:—We have made a number of fans with just a flat blade. To make this blade strong and free from vibration we had to put a rib or groove on it, which being on the air-driving side decreased the efficiency to a certain extent. We can get a much stronger and at the same time more efficient blade by making the curve, since we do not have to groove it. In the tests we made in our experimental work we found we got a stiffer blade and one that did not retard the flow of air.

A Member:—What angle do you use?

Mr. Hoyt:—We have angles of 30 deg.; that is, the radius is 3 in. and the arc is on a 30-deg. angle.

A Member:—What minimum clearance do you allow between the fan and the inside of the shroud where you have an eccentric for taking up the belt?

Mr. Hoyt:—It is good practice to allow for taking at least 1½ in. out of the belt length, and to do this the centers should be changed ¾ in. on each side of the belt.

Chairman H. C. Buffington:—What effect has the square corner of a shroud on the drawing in of the air?

Mr. Hoyt:—The corners do not make much difference. It is well to make the shroud as nearly square as possible so that the fan will be equally spaced in height as well as in width. The great point on the fan shroud is the angle from the radiator to the back of the shroud. I have shown this straight merely for simplicity.

Digitized by Google

CHAIRMAN BUFFINGTON:—What I had in mind was the possibility of creating a sort of eddy where the air would blow back through the radiator at the corners.

MR. HOYT:—You will not have that to any great extent if you place the back of the fan shroud flush with the back of the blades. It hits that angle of the shroud and returns. In my work I have tested this with some light material and I find it will pull in the center of the radiator and blow away at the corners.

A MEMBER:—I notice that in one case the air is drawn in from the outside of the fan blades. In tests I have made with fans I have always found the opposite to be true. I have blown smoke into the front of the fan and had it thrown away from the blades.

MR. HOYT:—The trouble was that you used pretty light material. There is so much air carried into and whirled around in the fan that it would be almost impossible to determine the flow of air definitely from your experiment. The test from which the curve was derived was made with an anemometer. The curved blade creates a vacuum in the back of the blade. It is a thing hard to explain but it can be shown nicely with the anemometer.

A MEMBER:—Is there not a critical speed for fans?

MR. HOYT:—We do not recommend fan speeds higher than 2000 r.p.m. with the engine traveling at the average speed. In passenger cars with engines that will run up as high as 2000, 2100 or 2200 r.p.m. on the road, the fan speed will be 3000 to 3500 r.p.m., but these conditions exist only at the highest speeds and do not last long enough to do harm. A fan will run much higher than an engine can force it, if consideration is given to the speed.

A MEMBER:—What would be the difference between an 18-in. fan with 1½-in. projected area and a 15-in. fan with 2-in. projected area?

MR. HOYT:—If the same volume of air is carried, there is not much difference in horsepower. I think the larger fan would take more horsepower. That particular point is shown on the charts.

A MEMBER:—When you increase the projected area, do you not also increase the width of the blade?

MR. HOYT:—That depends upon how far we go. With our spiders we can increase from 1½ to 1⅞ in. by using a 3 and 3 5/16-in. blade width. If we go above these dimensions we have to use a 4-in. blade. That is the width of the blade making 2¼-in. projection.

Digitized by Google

A MEMBER:—How many blades do you find necessary?

MR. HOYT:—Our best results have been secured with a four-blade fan. We can go as high as five blades and not have any great amount of trouble. Six or eight blades are too many; they chop up the air, and leave the space between the blades too small. We find that for production, efficiency and speed the four-blade fan is satisfactory. We can go to two blades, but here the speed has to be increased to such an extent that the bearings suffer.

MR. NELSON:—Suppose you curve the end of the blade a little on the farther corner, making it like a centrifugal fan; would it not have a tendency to push air out instead of drawing it in?

MR. HOYT:—It would make a difference, but I cannot say just what it would be, as I have not tried out that shape.

A. W. SCARRATT:—I have always believed that a fan is purely and simply a propeller, and the efficiency of it, therefore, the direct result of the thrust capacity it is able to develop. In every type of propeller now considered efficient the spiral form of blade is used. Why does that type of blade not succeed in ordinary fan design?

MR. HOYT:—The propeller type of blade is a good proposition, and I know of at least two firms that are using it for new fans. It requires an elaborate set of dies, which adds to the initial cost, and is somewhat heavier, but it is as efficient as the other type of fan. The curved type of blade gives a good stiff fan, which was our reason for using it.

LOUIS SCHWITZER:—Mr. Hoyt's statements with regard to end thrust appear questionable to me and the charts showing the amount of it seem somewhat misleading. He says that a fan running in free air will produce a certain end thrust, but that when this fan is placed back of a radiator the end thrust is increased about 25 per cent, depending upon the restriction of the air passage. It is a fact established upon a physical law that the pressure exerted by a moving air column, the end thrust, is a direct function of the air velocity. In other words, with an increase of the air velocity the pressure, or end thrust, increases. If a fan is placed behind a radiator, the air velocity produced by the fan is considerably less than in free air, on account of the air-passage restriction. If Mr. Hoyt's contentions are correct, with the air intake restricted to such an extent that no air could be delivered, the end-thrust load would be infinitely large. This

Digitized by Google

would be unreasonable, because the pressure exerted by a moving air column per square foot is

$Pt = 5.2\ h$; where
$P =$ the pressure in pounds
$t =$ the time in seconds
$h =$ the velocity-head in inches of water

The velocity of air in feet per minute is

$$V = 4000\sqrt{h} \text{ or, } h = \frac{V^2}{16{,}000{,}000}$$

From this formula

$$Pt = 5.2 \times \frac{V^2}{16{,}000{,}000}$$

This shows that the pressure exerted by a moving column of air is practically in direct proportion to the square of the velocity.

Mr. Hoyt states that he made the tests to determine the end-thrust load by using an indicator on the end of a 5-hp. electric motor shaft, to which the fan blade was directly coupled. In my opinion the only way to measure the end-thrust load on a propeller-type fan is to measure it directly on the fan. This can be done either by measuring the pressure of the air column delivered by the fan, or by mounting the fan movably on its spindle so that it exerts its pressure on a scale, through its motion in the opposite direction from that of the air current. It is also a very easy matter to determine the end-thrust loads by the horsepower input to the fan and the air velocity thus produced. The charts in the original paper also show that the end thrust drops faster than does the air velocity; in other words, by restricting the inlet the end-thrust load will be diminished faster than the air velocity diminishes. All of these curves show end-thrust loads of fans moving in free air. The manufacturer is more interested in knowing what end-thrust loads are produced in a fan behind a radiator, than in those obtained in free air or in a wind tunnel.

From actual tests and measurements on nearly 400 different makes of passenger cars, trucks and tractors, I have found that on about 80 per cent of these the maximum average air velocities obtained through the radiator are below 1500 ft. per min., on about 17 per cent they are between 1500 and 1900 ft. per min. and on only 3 per cent

Digitized by Google

are they above 2000 ft. per min. The highest velocity I ever found was 2200 ft. per min. These are the air velocities that must be taken into consideration in determining the end-thrust loads in radiator fans under actual operating conditions. It will be found from Mr. Hoyt's charts that on a 16-in. fan, considering even the maximum obtainable average air velocity of 2000 ft. per min., the end-thrust load will not be more than 3 lb.; on an 18-in. fan it will be about 3¼ lb., and for 20 and 22-in. fans Mr. Hoyt does not show air velocities as low as the maximum velocities actually obtained with these sizes of fans on automotive vehicles. In the case of the 22-in. fan the velocity and end-thrust curves start with 2600 ft. per min. and a corresponding end thrust of about 6.8 lb. I believe that no truck or tractor can be found where air velocities of 2600 ft. per min. through the radiator can be measured. In passenger cars, where this or higher air velocities through the radiator can be produced, it is only done at high vehicle speed. At these speeds, however, the initial air velocities produced by the motion of the vehicle tend to drive the fan and balance the end thrust produced by the fan itself. In any event, it is shown by the charts that the end-thrust loads in radiator fans for the air velocities actually produced in automotive apparatus, will not exceed 2 to 3 lb. in 16-in., 3 to 4 lb. in 18-in. and 4 to 5 lb. in 20 and 22-in. fans. This is one of the reasons why plain end-thrust arrangements have stood up so remarkably well in the field, as well as in laboratory tests up to an equivalent of 100,000 miles of driving.

With regard to the bearing question, a great many of the cup-and-cone type have been used, but their life is short, especially when they are abused. To drop a fan with cup-and-cone bearings upon the floor, or to drive it with only slight force into its supporting bracket, means the destruction of the races. Such bearings are also adjustable and, therefore, the matter of adjustability enters into the question. It takes an expert to know when these bearings are properly adjusted, and when not in proper relation with each other they are noisy and deteriorate rapidly. Slight wear lessens the efficiency of such bearings and carrying an end-thrust load in addition to the radial load results in considerably less radial-load carrying-capacity, which is the main load to be taken care of in cooling fans. The same arguments apply to annular-ball end-thrust bearings. Plain end-thrust bearings with

Digitized by Google

an automatic adjustment according to the end-thrust load are the most successful according to a test recently made in which the plain end-thrust bearing ran for 109 hr. at 1500 r.p.m., without lubricant, with only a few score-marks, while the cup-and-cone bearing lasted only 11 hr. under exactly the same conditions.

Mr. Hoyt states correctly that about one out of ten people who drive cars ever oils the fan. Much less will they adjust stuffing-boxes, especially when these require special-size wrenches and are inaccessible. With adjustable stuffing-boxes the felt invariably squeezes out between the shaft and the stuffing-nut, thus providing a wick oiler to drain the oil to the outside. Self-contained felt arrangements on the inside of the hub, which throw the oil they wipe off the shaft back into the bearing are, in my opinion, the most simple and successful type.

With regard to the distance of the fan from the radiator, it is not practicable to define this distance specifically. The most efficient distance depends upon the type of radiator core with regard to its air resistance, upon its size relative to the diameter of the fan and whether the fan is with or without a shroud. In the tests at Washington, with which I was connected, I found, for instance, that a 20-in. fan behind a 25 by 26-in. radiator showed highest air velocity through the radiator at a distance of 1½ in., while the same fan, within a shroud, behind the same radiator, showed the maximum efficiency at a distance of about 3 in. from the radiator. This efficiency was barely influenced by moving the fan either 1 in. toward or away from the radiator core. I contend that the best distance should be determined by experiment in each individual case.

Digitized by Google

TRACTOR DRAWBAR IMPLEMENTS AND THEIR HITCHES

By F N G Kranich[1]

THE author believes a more thorough understanding of the functions and use of drawbar implements is necessary. The tractor is incidental to agriculture. The implements used with tractors do the actual work and the tractor is a means to that end. Many tractors are sold on the quality of work done by the implements, and not because of their own work. Many a tractor is condemned because the implement combination is not correct. The amount of draft of plows must be thoroughly understood. Good plowing requires considerably more power than poor plowing, although done at the same depth and width. Turning the same number of square inches of furrow section will in one case require from 20 to 30 per cent more power than in another.

The tractor maker is not as familiar with the problem of hitching to implements as he should be; he feels that the implement is only incidental, can be hitched anywhere and still give good results; his principal object is to produce a tractor that will operate and pull implements. This idea is wrong. There is no one point on a tractor, either vertically or horizontally, that will serve as a hitching place for all implements and serve them equally well. It is the implement that must be given the consideration it deserves, for correct performance.

If tractor designers devoted more attention to the implements that tractors are to haul, trying to meet conditions as they are, more progress would be made, the combinations would serve the farmer better, power farming would become better established and better results would be obtained from the combination of tractors and implements.

The implements that go with a tractor have apparently not as a class received the consideration due to them. We see advertisements of the tractor everywhere. Pictures of tractors are published with details underneath of an excellent job of plowing or per-

[1]Agricultural engineer, Hyatt Roller Bearing Co., Chicago, Ill.

Digitized by Google

fect disking; pictures of them harvesting and a legend of the excellent job of harvesting being done.

All this seems to me a rather false pretense, because it is the implement that really does the work the farmer has to do, and although the tractor draws it or pushes it, whichever the case may be, the work that is being done by the implement makes for the success of the powerplant as a whole. At a demonstration the farmer will invariably look at the job of plowing. In fact, it is not uncommon to find that tractors are purchased because of a job of plowing that was done by the plow. That alone ought to bring us to a fuller realization of the fact that the implement which goes with the tractor is a big part of the program we have to work out.

I have heard tractor designers say that they had not thought of making certain parts to suit farm machines, because these were part of the implement and the implement men could readily adapt the implement to suit the tractors. I believe that the sooner we realize that the implement has a function to perform as important as that of the tractor which furnishes the power, the better it will be for the industry as a whole. We all know of a great many implements that cause loss and make trouble for the tractor. Much of this is due to the way in which the combination goes together; in other words, the way it is hitched. The whole program of feeding the world, which we have in agriculture, is largely dependent on the work of farm implements. They really do the farming.

Importance of Machinery in Farming

The history of the nation as a whole is nothing more than the history of its agriculture and consequently of its farm machinery. Go back as far as we may, we find that civilization has grown only as fast as farm machinery has been developed. Farming machinery governs the growth of agriculture and is far more important in the program we are concerned with than the tractor.

The value of the implement as an accessory to the farmer's labor is seen in the fact that a bushel of wheat is now produced in 10 min., whereas with the old hand method this took 3 hr. and 3 min.; corn is now produced in 41 min. as compared with 4½ hr., and corn shelling has been reduced from 100 min. per bu. to 1 min. To cut an acre of hay once took 11 hr., whereas this is now

Digitized by Google

done in 1½ hr. All this improvement is due entirely to the work of the implement as a part of farming.

The whole answer to the question of food production is *machinery*. It has become an invaluable part of the farm operator's equipment, and the tractor comes in as an accessory. We find some automotive apparatus that has really become a part of the farm machinery. This is particularly true of the motor cultivator. About 83 per cent of farm work is machine work; that is about the percentage of the labor put on a growing crop. This makes me all the more sure that farm machinery will receive greater consideration from the builders of automotive apparatus. To the draft implements as well as the belt machines, there is a certain relation we cannot get away from. The tractor is, after all, just a means to an end. It enables the farmer to get more out of his implements and tools, to use larger units of these and to do more work than he could otherwise in the same time.

With the aid of all this machinery automotive apparatus being, if you will, combined with it, we produce about two-fifths of the world's wheat, more than half of the cotton and over three-fourths of the corn. We are only one-sixteenth of the human race and only about a third of our people live on farms. What we accomplish is due to the development of machinery. Today one man can do the work that it took thirty men to do in 1880.

Evolution of Agricultural Machinery

I have read somewhere that the evolution of machinery in connection with agriculture can be divided into (*a*) the period of hand methods, when everything was done by man power, and crudely; (*b*) the period of transition, when some general machinery came into use for the heavier work; and (*c*) the period of fully adopted farm machinery. We are ready now to add another, (*d*) the period of automotive farm power. Farm power has become a part of agricultural progress.

Plowing, it has been said, is "the peak load in agriculture." We learn that it takes more power to plow the fields each year than is used in the combined industrial plants of the country during the same time. To plow even an acre of ground with the common 14-in. walking plow requires walking 8½ miles, and to cover 1 sq. mile we have to walk over 5000 miles. The tractor

Digitized by Google

is doing away with that hard, slow work. It is a part of the modern development, a means to an end.

The types of plow in use are various, but not so numerous as formerly. One plow manufacturer told me recently that formerly he had over thirty different types of bottoms in his different branch houses to suit the requirements of the territories in which his product was sold, whereas now, since the tractor has become a big part of his business, he has but six. Special bottoms have now become really a whim of either the branch manager or the farmer. There are two main types of plows, the flexible-beam, each beam fastened to the bottom independently, and the rigid-beam, all beams on one frame and traveling together. It has been found that where the land is very irregular and yet a constant depth of plowing is to be maintained, the flexible-beam plow gives better satisfaction, particularly if large units can be used, say four, six or eight plows. These, however, are very difficult to adjust, and since they come knocked-down, a pretty good plowman is required to set one up and get it properly adjusted to the work. The ordinary rigid-beam plow, used commonly with the small tractor, is comparatively simple. There is but one way to set it up and the directions are explicit.

Bottoms vary, of course, with the work the farmer has to do. To plow well, it is necessary that the action of the soil on the plow bottom be such that the soil will loosen up and disintegrate. In other words, the particles of soil should separate and tend to pulverize. This is essential and brings us to a fuller realization of the important function a plow has to perform. It has certain work to do. Perhaps this can best be likened to bending of the sliding leaves of a book one on the other. It is a big part of the plow manufacturer's problem to make a mold-board of such shape that it will turn the furrow slice, one particle on the other, and mellow it.

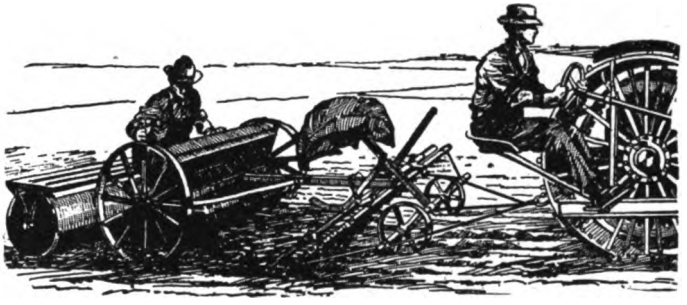
Hitching

The hitching of a plow to any sort of tractor frequently defeats all the work that the plowman has put in on the bottom. Perhaps most of us who go to demonstrations have noticed this every year. We find plows of the same make, in practically the same soil and at same speed, doing work of very different quality. To any one watching the demonstration last season at Salina, this was apparent. The variation was caused by the fact

Digitized by Google

that the plows were hitched differently. To know just how plows should be hitched to get the best results is difficult to determine.

The tractor man, of course, wants a hitch in the center. That is ideal. His purpose is to make the best showing for the tractor. The plowman wants to hitch in what he calls the "center line of draft." The plow that has been designed for that runs best and does its best work when hitched that way. Professor Sanbourn, in some tests in Missouri, found that 55 per cent of the total draft of the plows was used to cut the furrow, 35 per cent in friction of the sole and heel on the soil and 10 per cent in lifting load. At the Winnipeg tests made several years ago two gangs of men plowed in adjacent



TYPICAL EXAMPLE OF IMPLEMENT HITCHES

fields, cutting the same depth with the same number of bottoms, being checked by the same observer, yet the final result showed the draft of one gang to be about 50 per cent more than that of the other. It was found to be a question of proper hitching and sharp plows. The load on all three wheels of the plows should be equal. Any operator can check this readily by taking hold of the wheels and slipping them on the ground, determining whether a plow is set right. The rear wheel bothers most of us. The draft of the plow can ordinarily be increased as much as 20 per cent by having the rear wheel set wrongly, the plow riding on the sole or the heel. Most plows have a loose piece on the rear end of the land side that can be removed and changed as it wears. This piece frequently rubs on the bottom of the furrow. The tractor operator can easily adjust the rear

Digitized by Google

wheel on nearly all modern plows; provision is made for just that thing. We can make the best showing by getting a proper hitch and properly adjusting the plow.

Draft of Implements and Tractors

The draft varies all the way from 3 to in excess of 20 lb. per sq. in. of furrow section. In sandy soils, like those in Michigan and around the lakes, the draft will run 3 lb.; in some soils in Illinois and Texas 20 lb.; and in the West much more. It is, therefore, well worth while to train operators to understand thoroughly the hitching of the plows. It is important that the plow be so set that the tractor can do its best work. We find tractors advertised as two-plow, three-plow and four-plow, but in practice in some conditions "two-plow" tractors will hardly pull one bottom. In other cases they can pull three.

The center line of draft on plows is often talked of mysteriously. It is assumed by most plowmen that this center line of draft is about 2 in. inside the land side of a bottom, and in the same proportion in two, three and four-bottom units. Some tests were made this summer by Professor White to find the center line of draft on a plow; in other words, to determine definitely the point of least resistance, rather than assume it to be "2-in." position. I had the privilege of working with him. The test disclosed some curious things. We had a tractor with a drawbar the total width of the machine, with holes punched in it every 2 in. all the way across; in other words, a drawbar that gave us an opportunity to hitch from the outside of one wheel on the right to the outside of the other wheel on the left. The purpose was to take two, three and four bottom gangs, move the hitch and make dynamometer tests to find the point where the plow pulled "lightest," the assumption being that this would naturally indicate the line of least resistance—in other words, the center line of draft. We found, however, that the hitch by which the plow could be pulled most easily did not necessarily determine the center line of draft. The plow ran lightest when it was hitched on one side, but the quality of the plowing was very bad. We found that this was due to the fact that the plow was hitched badly. This was evident even in a photograph. It was such a poor job of plowing that I believe the farmer would have ordered us off the field if we had not contracted to do the work to his satisfaction.

Digitized by Google

This revealed to us the importance of getting the two units coupled in harmony. We found that one hitch gave a draft of 1800 lb. on a four-bottom plow. That same plow hitched on the other side had a draft of 2395 lb., an increase of 44 per cent. We measured the depth every 40 rods across the field. In another case the decrease in the draft due to a good hitch was a trifle over 30 per cent. We found that on one three-bottom plow the draft was decreased 22.1 per cent by a good hitch; on a two-bottom, 17.4 per cent. These figures emphasize the importance of this matter. A tractor can be made to show good or bad performance simply by hitching correctly or incorrectly. A statement of test results that does not include mention of the conditions under which the tests were made is of little value. It is not convincing to state that one tractor used less fuel than another in plowing; that in one unexplained case it cost 7 cents an acre and in another 12 cents. Very seldom, in any plowing tests or demonstrations, going back even as far as the Winnipeg contest, has the relation of hitch and draft been recorded or considered. I know it was not at Salina or at Fremont. Even in the work that was done at Fremont two years ago, no record of the draft was kept so far as the hitch was concerned. We should all realize that the point is important. If manufacturers propose to publish figures of results of tests of this sort, the item of hitch, since the draft can be so affected by it, should be included.

Not much work has been done, at least for publication, to get the draft of other implements that go with the tractor. Plowing is, of course, the big work the farmer has to do, the work with which he is most concerned; yet he is using the tractor for other things; he must do so to make it of real economic value to him. Tractors are made to use with the present line of implements, but I think that not many farmers have found it profitable to use a tractor and two or three mowers, with a man on the tractor and one on each mower. The solution of this part of the problem is larger units for the men to handle. A 10-ft. mower instead of two 5-ft. ones does much better work, and better hitches can be made to reduce the side-draft on the tractor. A 10-ft. disk harrow, just as sharp as practicable, required a 790-lb. pull to disk-plow ground. A 10-ft. pulverizer took 700 lb. The binders, mowers and drags run very light in draft as compared with plows.

Digitized by Google

If plows are properly hitched, nine-tenths of the complaint of high cost of plowing will, I think, be eliminated, because we can then plow more cheaply, needing less drawbar horsepower and, of course, less fuel. The thing that appeals to me most in the whole situation is the question of tractor hitch to suit the implement. As I have said, if the men who sell tractors would give more attention to the implement the industry as a whole would gain.

VARIABLE-SPEED GOVERNORS

By W W Wells[1]

THE ordinary governor used on trucks and tractors is essentially a one-speed device. It gives good results at one speed, but at higher speeds "hunting" develops and at lower speeds governing is less accurate. This is because the spring must be stiff enough for maximum speed, and hence four times stiffer than it should be for half speed.

The paper shows by calculations and curves the best results that can possibly be obtained; also, curves from a test showing what results are actually obtained with one well-known governor. Two new types of governor are described, in which the position of the spring is varied for different speeds. Theoretical curves also are presented and the results of tests, indicating that the new types produce the same character of curve at 800 as at 1600 r.p.m.

Some years ago, I think in 1903, while I was employed by the Ball engine people, they equipped some engines intended for use in a paper mill with a governor that was adapted to allow the engine to run at a variety of speeds. This was done by taking an ordinary Pickering governor and driving it by a speed-changing pulley. As I recall it, the requirements of the paper mill were that the engine should be able to govern through a wide range of speeds. With the speed-chang-

[1]Engineer, Clyde Cars Co., Clyde, Ohio.

Digitized by Google

ing pulley the ratio of the drive between the engine shaft and the governor could be varied, and, since it was the speed of the governor shaft that determined the position of the throttle, the governor shaft ran always at the same speed, while the engine ran anywhere from perhaps 600 to 200 r.p.m.

I wish to call your attention in the first place to the formula for centrifugal force. This is

$$F = 0.0000284\ WRN^2, \text{ in which}$$

W = weight in pounds
R = radius or distance from the axis in inches
N = number of r.p.m.

When we design a governor, W becomes constant and R varies according to the position of the throttle. With the weights in the inner position the throttle is open, and the weights move out a certain amount in closing the throttle; hence R varies within a definite range. The force varies also as the square of the number of revolutions. If we are figuring on one speed only, all the factors except R become constant and our problem is comparatively simple, because we can make a spring the pull of which will increase at the same rate as R increases. If, however, we want to govern accurately at different speeds, our spring must have characteristics for the high speed which differ from those for the low rate. Since the force varies as the square of the number of revolutions, if we double the speed we quadruple the force, and since the centrifugal force is balanced by the spring, we must quadruple the spring pressure. As the increase in centrifugal force, due to the increase in R, is four times as great, we need a spring that is four times as stiff. Doubling the speed requires a spring pressure four times as great and a spring stiffness four times as great.

Most governors are adjustable, that is, you can increase or decrease the pressure on the spring, but the stiffness remains the same and is correct for but one speed. To make this a little more concrete, let us assume that we have two weights of exactly 1 lb. each and that when they are in their inner position they are 1 in. from the axis and in their outer position the center of gravity is 1½ in. from the axis. Assume also that the leverage with which the weights act on the spring is unity; then

Digitized by Google

the pressure on the spring will be exactly equal to the sum of the centrifugal force of the two weights.

Let Pc and Po represent the force exerted by the spring when the throttle is closed and open respectively. Then, since

$$P = F \qquad W = 2$$
$$Rc = 1\tfrac{1}{2} \text{ and } Ro = 1$$

we can substitute these values in the formula for centrifugal force ($F = 0.0000284WRN^2$) and we shall have for this arrangement of weights

$$Pc = 0.0000852\ Nc^2 \tag{1}$$
$$Po = 0.0000568\ No^2 \tag{2}$$

If we wish this governor to control the speed within 2 per cent when the idling speed is 1600 r.p.m., we will make Nc 1600 and No 1568. Substituting in equations (1) and (2) we have $Pc = 218$; $Po = 140$; hence

$$Pc - Po = 78.$$

Since the movement of the spring is ½ in., its stiffness should be 156 lb. per in. For convenience let us use a 160-lb. spring. This will cause a drop in speed of about 2½ per cent; then

$$Pc - Po = 80 \tag{3}$$

Equation (3) holds as long as we use a 160-lb. spring, and these three equations will enable us to calculate the variation in speed as the load varies for any setting. The table shows the results for a number of different settings. When set to run idle at 1599 r.p.m., the speed falls to 1558 when the throttle is wide open. We could tighten the spring enough to make the idling speed 1700 r.p.m.; the speed under load would then be 1709, and we should have an extreme case of hunting, since we would be trying to make the engine run faster when fully loaded than when idle. If we back off the spring adjustment to make the idling speed 1400 r.p.m., it drops to 1237 under load. If set to idle at 800 r.p.m., the throttle never gets wide open.

Throttle Opening and Engine Power

This is not the whole story, however. The case is not quite as bad as it looks, due to the fact that it is not

Digitized by Google

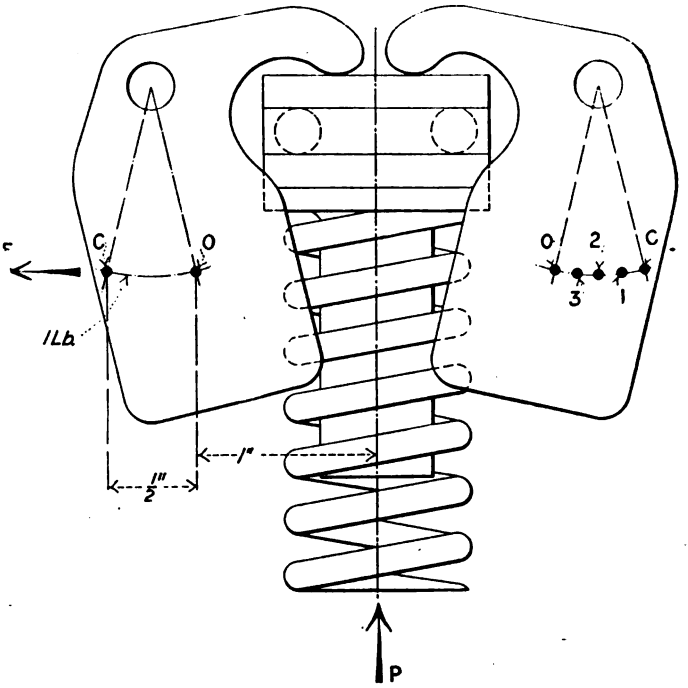
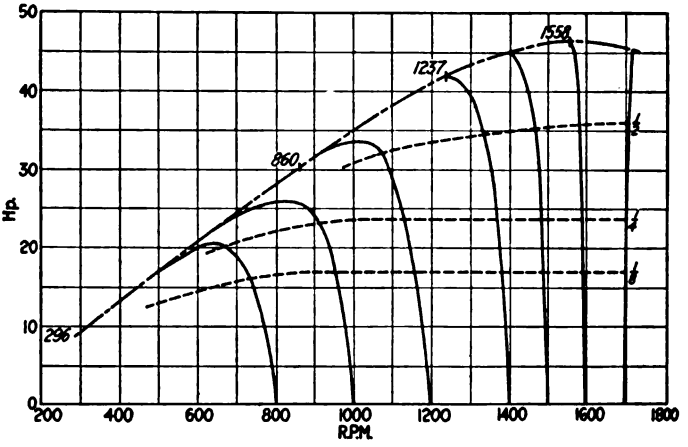


DIAGRAM SHOWING TYPICAL RELATION OF GOVERNOR WEIGHTS AND SPRING

necessary to have the throttle wide open at low speeds to get almost the full power of the engine. In making a test of a governor in which a butterfly throttle was used, we measured the position of the arm operating the throttle at each reading and found that when the weights had moved a quarter way out the engine was developing about 20 hp. whether the speed was 800 or 1600 r.p.m., and with the weights half-way out the power was 30 hp. or more at speeds above 1000 r.p.m. When the weights were three-quarters out and the throttle three-fourths open we had very nearly the full power of the engine. I have made calculations for five different throttle positions by taking three points equally spaced between open and closed positions, i.e. making $R_o = 1$ in.; $R_s = 1\frac{1}{8}$ in.; $R_2 = 1\frac{1}{4}$ in.; $R_1 = 1\frac{3}{8}$ in.; $Rc = 1\frac{1}{2}$ in., and $Po + 20 = P_s$; $P_s + 20 = P_2$, etc., and find that when set for an idling speed of 1599 r.p.m. we have 1592 r.p.m.

Digitized by Google



CURVE OF THEORETICAL RESULTS OF SEVERAL DIFFERENT GOVERNOR SETTINGS

with throttle one-quarter open, 1583 at half throttle and 1558 with open throttle. These values if plotted show a drop of 7 r.p.m. at 20 hp., 16 at 35 hp. and 41 at full load; a total range of 2½ per cent. At 1500 r.p.m. the total drop is 97 r.p.m. or 6½ per cent, at 1400 r.p.m. 11½ per cent, and when idling at 1000 r.p.m. the speed falls off to 296 r.p.m. under load. The curve, however, instead of being a nearly horizontal straight line, takes the form shown, because the power runs up to 20 hp. during the first quarter of the throttle movement.

What I want to call your attention to here is the fact that it is impossible to govern anywhere near as closely at reduced speeds as at the speed for which the governor is designed, although this defect is minimized somewhat by the fact that we do not need full throttle opening at low speeds.

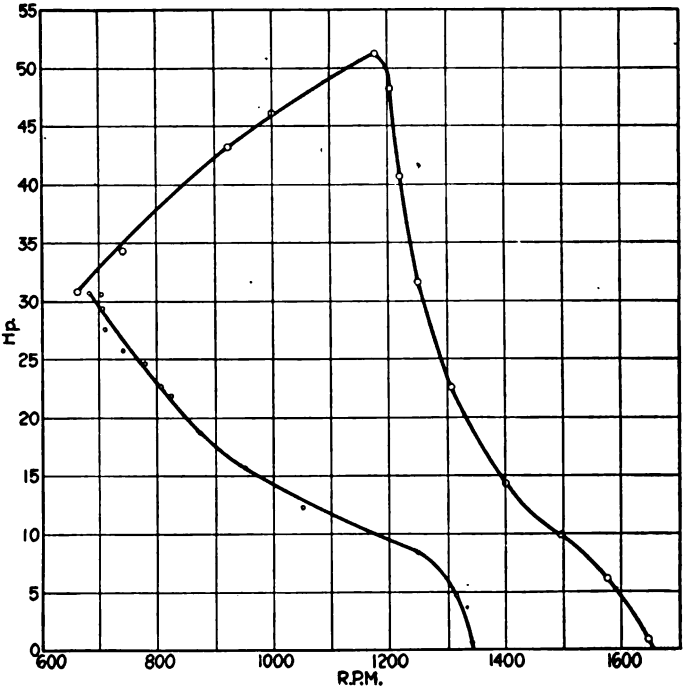
Now the above is theory, but it represents a limit that we cannot hope to exceed with the usual method of mounting the spring. Another set of curves shown represents practice, the results of a test of a well-known engine with its governor adjusted for maximum and minimum speeds. The shape of these curves is not ideal and no doubt can be improved considerably; what I am concerned with is the fact that when set for maximum speed, the upper part of the curve is nearly vertical, while at the low-speed setting the inclination is very marked.

Digitized by Google

Throttle,	Open	¾	½	¼	Closed	Increase, per cent
Speed, r.p.m.,	1,709.5	1,706.1	1,703.3	1,701.1	1,699.2	—0.6
	1,558.6	1,572.4	1,583.3	1,592.2	1,599.6	2.5
	1,404.2	1,437.2	1,461.5	1,484.0	1,501.2	6.4
	1,237.0	1,294.0	1,336.0	1,372.0	1,400.0	11.6
	860.0	985.0	1,074.0	1,129.0	1,196.0	24.0
	296.0	625.0	796.0	912.0	999.0	70.0
	.....	28.0	459.0	669.0	803.0	....

The governing is satisfactory at high speed and heavy loads but poor at low speed for all loads.

Let us go back to equation (3) representing the variation in spring pressure due to movement of the weights. This holds no matter how the governor may be set, because the spring has the same stiffness under all loads. It takes 20 lb. to compress it the first ⅛ in. and an additional 20 lb. for every added ⅛ in., and its movement is



RESULTS OF AN ENGINE TEST IN WHICH THE GOVERNOR WAS ADJUSTED FOR MAXIMUM AND MINIMUM SPEEDS

Digitized by Google

always ½ in. as the throttle moves from open to closed positions. For isochronous governing $Nc = No$, therefore, from (1) and (2), $Pc/Po = 1\frac{1}{2}$, or, in general terms, the ratio of Pc and Po must be a constant, but from (3) we see that the difference is a constant. Both of these conditions can be satisfied at only one speed. To get a governor that will govern accurately through a wide range of speeds we might (*a*) use a spring that is stiffer under heavy loads or (*b*) mount the spring in such a way that it will be moved farther at high speeds than at low ones. Either method will get away from equation (3).

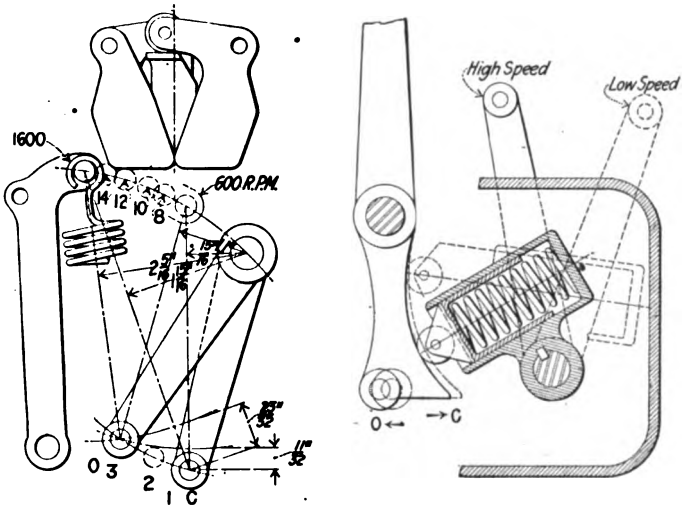
I have made some sketches of a governor of the first type, but have not as yet built any that way. We have worked out two slightly different designs in which the travel of the spring varies according to the speed at which the engine is running. One of these has been in use on the Clydesdale trucks for a number of years. Our weights are inside the housing and are very similar to those you find in almost any flyball governor. The shaft carrying the arm seen at the right is connected at the other end to the throttle in the carbureter. Clockwise motion opens the throttle. The centrifugal force of the weights tends to rock the shaft in a counter-clockwise direction. The spring is attached to the lower end of this arm and its other end is carried by the upper end of the lever at the left. This lever rocks on a fixed support at its lower end. Moving this lever to the left stretches the spring and at the same time moves it away from the shaft, so that the leverage with which it acts on the shaft is increased. This increase in leverage has the same effect on the rocker-shaft as increasing the stiffness of the spring would have if there were no change in leverage. I have spoken of the extension of the spring as being greater at high speeds than at low. In this case, with the spring lever set for high speed, the spring is stretched 23/32 in. as the throttle closes, while at the low-speed setting it is only 11/32 in. If we allow the spring lever to swing to the right until the center line of the spring intersects the axis of the shaft we will have a spring movement of 0 in., leverage 0 in., spring pull 0 lb., and speed 0 r.p.m.

Test Results of Two Types of Governor

The test proved that this governor is not quite as well proportioned as it might be, and I have since made some calculations on another governor of this type in which I

Digitized by Google

expect to get better results. This too is theory; it has not yet been reduced to practice. This shows for the idling position, one-quarter throttle opening, one-half, three-quarters and full-open throttle, 1616, 1605, 1590, 1555 and 1480 r.p.m. This means 8½ per cent total variation. At another setting the speeds are 1159, 1141, 1118, 1086 and 1028 r.p.m., or 11½ per cent variation. At 600 r.p.m. we get 21 per cent variation, but we use only half of that, since we do not require the full opening of the throttle at that speed. It may be possible to straighten out these curves by rearranging the parts

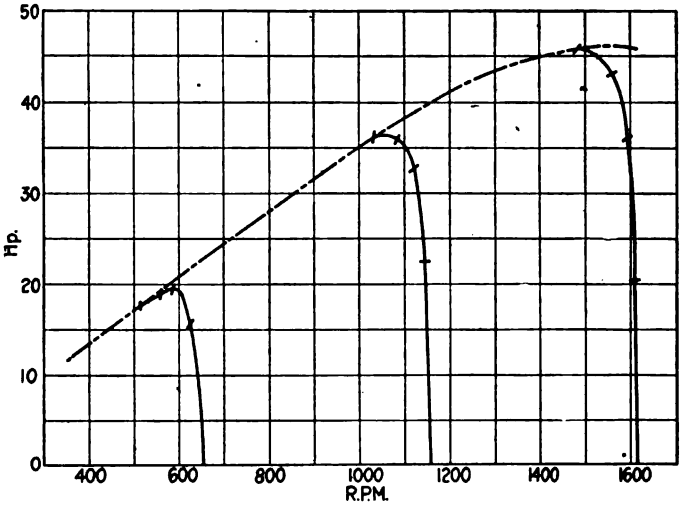


DETAILS OF A NEW TYPE OF GOVERNOR

connecting the weights to the throttle so as to make the movement of the weights more nearly proportional to the power the engine develops.

But to return to practice. A test of our present tension spring design of governor gives results as shown. The shape of these curves is not ideal, but it is about as good as any governor curves that I have seen. Notice, however, that the shape of the curves for 1600, 1400, 1200, 1000 and 800 r.p.m. is almost identical. There is one feature of the design that may prevent us from getting ideal results at all speeds, and that is the fact that

Digitized by Google



THEORETICAL RESULTS WITH A NEW TYPE OF GOVERNOR

the distance from the axis of the rocker-shaft to the center line of the spring varies somewhat as the arm changes its position.

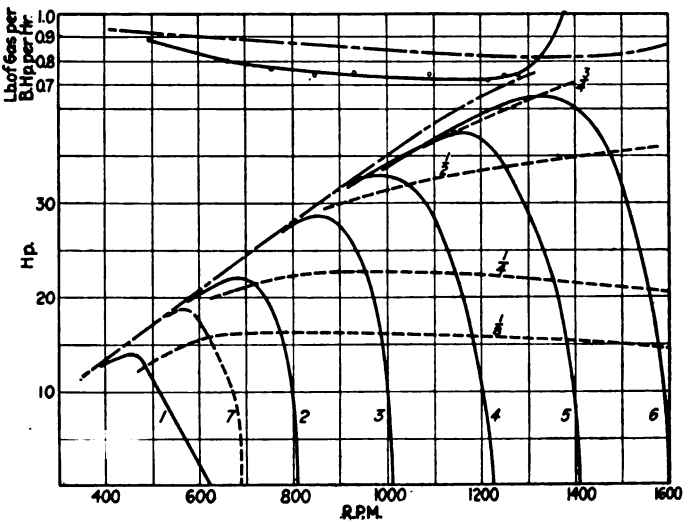
Throttle,	Open	¾	½	¼	Closed	Increase, per cent
Speed, r.p.m.,	1,868	1,954	1,988	2,000	2,001	6.5
	1,480	1,555	1,590	1,605	1,616	8.5
	1,028	1,086	1,118	1,141	1,159	11.5
	512	554	588	623	654	21.0

There is one result shown by this test for which I have no satisfactory explanation. The broken line shows the horsepower curve with the governor disconnected and the throttle held wide open. Each test with the governor was made by increasing the load until the throttle was wide open, and in most cases until the speed was reduced to 500 r.p.m. or less. The gasoline consumption was determined at each reading and the results are plotted on the diagram. The broken line shows results with the governor disconnected, the lowest value being 0.82 lb. per hp.-hr. The full lines show results with the governor controlling the throttle, the lowest value being 0.70 lb. per hp.-hr., and it is only after the throttle is about half closed that the consumption exceeds that shown with the

Digitized by Google

governor disconnected. We do not claim a 12 per cent increase in fuel economy, although these figures seem to prove it. I had thought that this result might be explained on the ground that the carbureter is less efficient when the throttle is wide open than when nearly but not quite wide open, but a number of these runs were made with the governor holding the throttle wide open and yet reducing the fuel consumption.

We call this governor a "controller" to convey the idea that it does more than the ordinary governor used on motor trucks, and because it has complete control of the throttle at all times. It is connected directly to the throttle in the carbureter. We use no auxiliary throttle. The driver has no control of the throttle except through the controller. He sets his lever for the desired speed and then leaves the controller to manage the throttle. The spring lever is connected by a rock-back to the accelerator and to the throttle-lever on the steering-gear, so that the operation of a truck equipped with this governor is practically the same as on any truck where you have a combination of a hand-controlled throttle and a foot accelerator. If you are driving at a uniform rate on level road you might not realize that you had anything unusual, but when you strike a grade the truck keeps



ACTUAL TEST RESULTS OF A NEW TENSION SPRING TYPE GOVERNOR

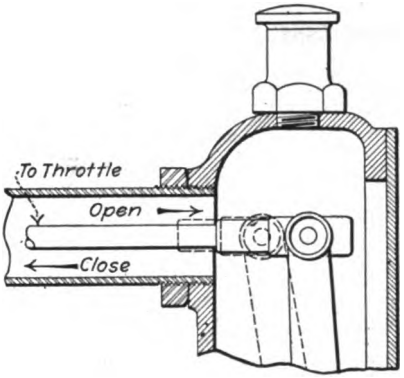
Digitized by Google

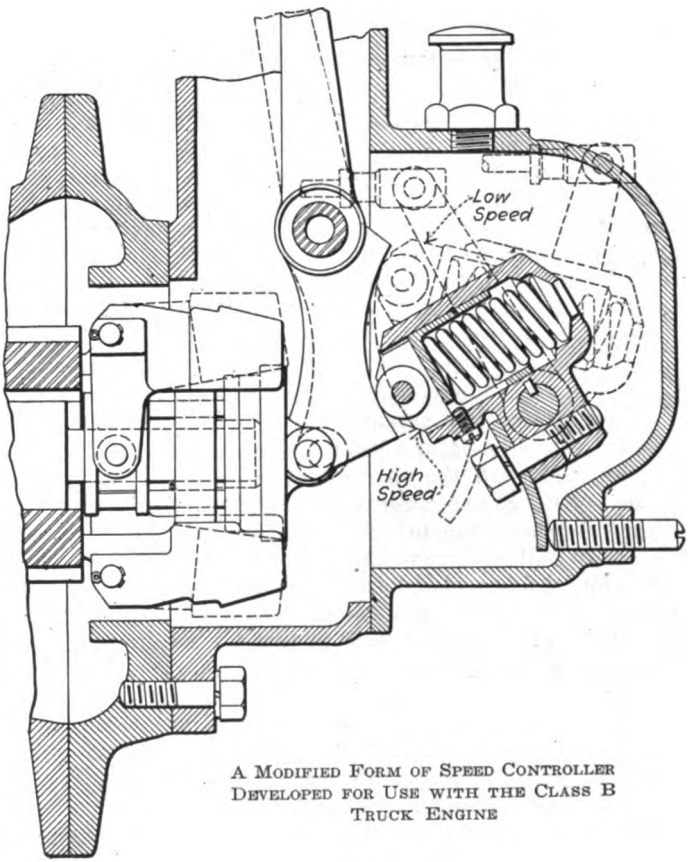
going at the same speed without any adjustment of the levers, and when you reach a down grade or throw out the clutch the engine does not speed up. The driver uses the lever to change the speed instead of to change the power. This is exactly the design that has been used on the Clydesdale trucks since 1914. This governor is mounted on the Continental model C or model E engines without any change in the design of the engine or any additions.

We are now building the slightly modified form illustrated for use on the Continental model B engine, which is the engine used on the Class B Government truck. We remove the spring ordinarily furnished with the governor, put in new weights and a compression spring working in a guide and operating through a roller on a cam surface on the lever. The full lines show the spring in the high-speed position. Here the spring is compressed considerably and is acting on the lever at some little distance from the fulcrum; hence it has considerable leverage. The spring and its housing are carried on a shaft that extends through the housing to a lever on the outside, which connects with the accelerator and hand lever on the steering-gear. Releasing the pull on this lever allows these parts to swing back to the position shown by broken lines; here the spring is compressed but little and is cating at a short distance from the fulcrum of the lever. This is the low-speed position. We are just beginning to sell trucks with this type and have not yet made a dynamometer test. So far as we can judge by the behavior of the truck, it is equal to the other type, and I believe can be made to give slightly better results.

Each of these types is provided with a stop screw that determines the maximum speed. When testing the truck we set this stop for the speed limit desired and fasten it with a seal. Some of you are probably thinking that the exposed working parts seen in the first type give a reckless driver a chance to hitch something on that will enable him to drive faster than the maximum for which the governor is set. The fact that the driver has no control of the engine except through the controller reduces this temptation considerably. If he puts it out of use he must rig up some other means for controlling the throttle. However, the drivers seem to like the controller very well. The design just described is completely housed, and the other could be so protected but not quite as easily

Digitized by Google





A Modified Form of Speed Controller Developed for Use with the Class B Truck Engine

Digitized by Google

THE DISCUSSION

CHAIRMAN H. C. BUFFINGTON:—Mr. Wells has described something that is extremely interesting. There are many places where governing at a certain speed is desirable; for instance in threshing, where pulleys are of different diameters and whatever is being operated is running faster. Here, it seems, the engine can be slowed down and still maintain a governing speed.

MR. WELLS:—I would like to ask one question. I notice in one of the tractor indexes under specifications of tractors built in Minneapolis, that the belt speeds vary from 2000 to something like 4700 ft. per min. The S. A. E. Standard, I understand, is 2600 ft. per min. Is the one speed satisfactory, and, if so, why is it not more commonly used?

CHAIRMAN BUFFINGTON:—I think that every firm manufacturing tractors is trying to get to that one speed. It must be remembered that this standard has been in existence for a short time only. It will take longer to consider and adopt it. I would like to ask just where a variable-speed governor will be worth the extra cost? The simpler a governor is, the fewer the moving parts, the more desirable it is, and one that will govern within 10 per cent will usually be satisfactory. On trucks a sensitive governor is not wanted for the reason that when stalled it is desirable to have the engine speed up a little.

MR. WELLS:—In one design of engine I have recently figured on, the additional cost would be for the spring lever and the boss to mount it on. The governor already has the rocker-shaft, the lever on the rocker-shaft which is connected with the throttle and the spring attached to the lever. It has a control quite similar to that used on a well-known tractor, which is entirely through the governor, with only one throttle, the one in the carbureter, but instead of the lever arrangement that we use it has a spring that pulls straight back. This means that the control is similar to ours but that the accuracy of the governing at low speed is decreased.

A. F. MOYER:—In designing the ordinary governor you run into hunting at high speeds and poor regulation at low rates. I believe that in arranging the spring to change the leverage for different conditions, Mr. Wells has something valuable.

MR. WELLS:—How much of a demand is there for variable speeds in tractor work? If there is as much

Digitized by Google

variation in land conditions elsewhere as we have in Michigan, some variation in speed would seem to be desirable, as well as some changes in speed for belt work. One belt speed can hardly be entirely satisfactory for all belt-driven machines any more than one speed is adapted to all kinds and conditions of soil and all kinds of farm work.

W. J. McVICKER:—A chance to regulate speeds might be desirable in some cases, especially in corn plowing. There it is needed in going across a field at 2 to 3 miles per hr. That is about the only place I can think of where it would be needed.

CHAIRMAN BUFFINGTON:—In plowing work I would be afraid of the variable-speed governor, because when you throttle an engine down you are overloading it. Naturally, a farmer will put on all the plows he can at the recommended governing speed of the machine. He will not use two plows at 2 miles an hr. when he can plow 3 miles per hr. I can see that variable speed is desirable in belt work where a fine-haired adjustment is demanded, but I question the cost. If there is to be little or no difference in cost and no more working parts are required, I should not hesitate to endorse it.

H. W. ADAMS:—I did considerable operating a few years ago while with a company that had a tractor with a variable-speed governor. The speed could be changed, as Mr. Wells has described, from the driver's seat, and it was one of the finest things I ever saw in a tractor. In plowing many different conditions of soil are met; sometimes you are in rocks and sometimes in stumps. If you have a one-man machine and come to a rough, rocky spot, you want a governor that can be set for from ½ to 2 miles per hr. The Twin City engine made a few years ago had a governor that could be changed from the seat. I believe that when Mr. McVicker was out in the country he satisfied himself that it was a good thing. I, personally, think it is very desirable that the operator have some means of changing the speed. If you can set a tractor to run, say, 1 mile per hr., you can go back, attend to the plows and pull out the rocks. You do not want the machine to stop; you want it to creep. Mr. Wells has something that is worth considerable to tractor manufacturers. I know it will meet with favor among the farmers, especially in uneven country. I believe it is a good thing.

MR. WELLS:—What Mr. Adams has said is right along the line of my experience. I had one field made up of

Digitized by Google

boulders and there I had the horses travel very slowly to save my ribs. In another field with light soil and not a boulder, I could put on a sulky plow and three horses and make them walk right along. There must have been a difference of 50 per cent in the speed under those conditions. I find myself questioning another condition. I have never operated a tractor plow. When the plow comes out of the ground, do you have to manipulate the throttle or do you set it in the position for maximum speed so that the governor will act? Would it not be more convenient at the turns to reduce the speed but still have it on to take up the load?

MR. ADAMS:—In a large machine with a number of plows and even where there is an extra man, the tractor is generally throttled down to run slowly and give the operator a chance to drop the plows. In that case it would be a good idea to have the governor maintain constant speed while the operator goes back to put in the plows and then jumps on. I believe it would be a good thing both in putting the plows into and taking them out of the ground, especially on a one-man machine.

MR. MCVICKER:—The greatest objection is that most engines are efficient at one speed only, and when you change this they operate at lower efficiency.

CHAIRMAN BUFFINGTON:—I am very glad Mr. McVicker brought that point out. In designing a tractor engine it is desirable to have the revolutions just above the point of maximum torque, so that when the engine has a maximum load it still maintains maximum torque. Below maximum torque the engine is overloaded and will pound. An engine operated at a speed of 400 r.p.m. is below its maximum torque and is overloaded.

Digitized by Google

GENERAL INDEX

A

PAGE

Adapting the fuel to the engine (E W Dean and J P Smootz) 683

Addresses

Baker, Col C B 592
Bartholomew, J B 499
Beecroft, David 500
Hedges, Hon Job E 34
Houston, George H 43
Johnston, Edward A 496
Kettering, C F 597
Manly, Charles M 40
Merrick, H H 591
Mount, Finley P 491
Peake, E E 590
Pogue, Joseph E 497
Reeves, Alfred 41
Willys, John N 39

Adjustment of aircraft radiators in flight 571
Adoption of naval aircraft program 374
Advantages of pneumatic tires 463
Aeronautic meeting at New York City 511

Aeronautics

Case for the airship (Ladislas d'Orcy) 521
Experimental engineering (Alexander Klemin) 447
Field of airships and airplanes 529
Long-distance flight 527
No retrogression to pre-war status 434

Agricultural Implements

Draft of 782
Evolution of 779
Hitching to 780
Tractor drawbar hitches for (F N G Kranich) 777

Air Cleaners

Carbureter (W G Clark) 745
Centrifugal type 754
Cloth or screen type obsolete 747
Inertia 748
Liquid trap 750
Screen type obsolete 747
Types of 746

Aircraft

Adjustment of radiators in flight 571
Aircraft radiators (Archibald Black) 534
Bends in radiator pipes 560
Bolt practice of Naval Aircraft Factory 322
British radiator tests 548
Bubbles in radiator cooling water 566
Bureau of Standards radiator tests 554
Changes in design and construction 324
Convoy escort 380
Cooling engines 302
Design of water pockets for radiators 566
Designing first engine 389
Effect of altitude on radiator performance 564
Engine development, effect on automobile practice (H M Crane) 137
Engine mounting 300
Engineering problems in Naval Factory 316
Field of airplanes and airships 529
Forward speed in climbing 569

Digitized by Google

PAGE

Future development 382
Future development by Navy 365
Laminated members 318
Liberty engine (J G Vincent) 385
Location of radiator 562
Mean temperature difference between air and cooling water 569
Miscellaneous radiator tests 558
Modern radiator installations 534
Modern radiators 537
Naval airships (Com J C Hunsaker) 578
Naval program adopted 374
Operations of naval (Com J H Towers) 373
Outside plants increase production 310
Patrols maintained by Germany 586
Patrols maintained by United States 376
Position of United States on development 531
Pressure cooling system for radiators 569
Problems of the Naval Factory during the war (Com F G Coburn) 304
Production Board's work 387
Radiator production considerations 571
Radiator materials 570
Radiators 534
Rail shipment undesirable 323
Section Technique Aeronautique radiator tests 542
Shutters for radiators 573
Source of spruce 323
Spark-plug dimensions 13
Special tools and fixtures 324
Theory of radiators 541
Velocity of air in slipstream 566
Weight of radiators 570
Women in production of 312
Wood defects a problem 320
Zeppelin 582

Air performance of Liberty engine 425
Airplane and seaplane engineering (Com H C Richardson) 333

Airplanes

Automobile not a competitor 436
Balance of engines 297
Beginnings of present-day 513
Commercial future from an engineer's standpoint (C H Day) 512
Commercial sizes and types 518
Comparison of airplane and automobile engines (H C Marmon) 146
Control and body differences from automobiles 155
Cost of construction and operation 515
Determining performance of 348
Effect of experience with war planes on automobile design (O E Hunt) 154
Engines, fixed radial cylinder for (John W Smith) 294
Engine in automobile 152
Engine service conditions compared with automobile 157
Factors to be considered in designing 515
Field of 529
Full-scale performance testing 457
Future development by Navy 365
Improvements in engine 442
Improvements in engines not suitable for cars 158
Industry abroad 679
Location of powerplant and crew 342
Making a utility (G C Loening) 433
Performance, factors affecting 338
Performance of Liberty engine 425
Performance predicted by wind tunnel tests 454
Power required 338
Practicability of high speeds 439
Propeller efficiency 346
Results of design and construction 160
Safety in landing 515
Sand tests of control surfaces 450
Structural strength 448
Types developed abroad 334
Wings, effect of size on performance 339
Wings, form and proportion of 344

Digitized by Google

Airships PAGE
Beginning of construction 579
Case for (Ladislas d'Orcy) 521
Field of 529
Long-distance flight 527
Naval (Com J C Hunsaker) 578
Position of United States on development 531
Progress since 1914 522
Zeppelin 582
Air washers 750
Alcohol, substitute engine fuel 206
ALDEN, H W, ON TANKS 46
Altitude, effect of, on radiator performance 564
American wooden ships 703
Ammunition body trucks 59
Armor for tanks 54

Artillery
Repair and supply trucks 60, 62
Wheeled tractor 62

Automobiles
Airplane engine improvements not applicable 158
Airplane engine in 152
Airplane not a competitor 436
Automotive Ordnance apparatus (Lieut-Col W G Wall) 59
Control and body differences from airplanes 155
Effect of aircraft engine development on (H M Crane) 137
Engines, comparison of airplane and (H C Marmon) 146
Factories of allied nations 670
Foreign post-war designs 676
Post-war designs 676
Probable effect of war airplane experience 154
Reconnaissance, machine gun and staff observation 64
Tire and road surface losses 278
Working conditions in factories abroad 674
Automotive applications of marine engines in the war (G F Crouch) 112
Automotive industry abroad, conditions in (David Beecroft) 669
Automotive Ordnance apparatus (Lieut-Col W G Wall) 59
Aviation, future of naval 382

B

BACHMAN, B B, ON PNEUMATIC TIRES ON TRUCKS 459
Baker, Col C B, address 592
BAKER, W C, ON CORRECT LOCATION OF BRAKE LEVERS 657
Ball and Roller Bearings Division report 2
Bartholomew, J B, address 499

Base Bands
Industrial truck wheels 25
Solid tires 22

Bearings
Angular contact ball 3
Annular ball, extra small series 3
Annular ball, separable (open) type 2
Cooling fan types 767
Crankshaft, sizes and loads 635
Load on crankshaft 635
Size of crankshaft 635
Beecroft, David, address 500
BEECROFT, DAVID, ON CONDITIONS IN THE AUTOMOTIVE INDUSTRY ABROAD 669
Beginning of airship construction 579
Beginnings of present-day airplanes 513
Belts, size of, for cooling fans 761
Benzol, substitute engine fuel 206
BLACK, ARCHIBALD, ON AIRCRAFT RADIATORS 534

Digitized by Google

PAGE

Bolts
Practice at Naval Aircraft Factory 322
Rebound clips, spacers and 17
Tolerances in spring 16
Brackets, frame 19

Brake-rod Gage
Function of 658
How used 659

Brakes
Correct location of levers (W C Baker) 657
Effect of load and road conditions 661
Error in application of, produced by incorrect length of rod 662
Influence of 630
Use of rod gage 659
Brake thermal efficiency 270
Bubbles in cooling water 566
BURKHARDT, O M, ON PROGRESSIVE AND RETROGRESSIVE DESIGNING 623

C

Camshaft housing in Liberty engine 410
Carbureter air cleaners (W G Clark) 745

Carbureters
Air washers 750
Centrifugal air cleaners 754
Cloth or screen type air cleaners obsolete 747
Inertia air cleaners 748
Liquid trap air cleaners 750
Screen type air cleaner obsolete 747
Types of air cleaners 746
Carburetion, Liberty engine 416
Case for the airship (Ladislas d'Orcy) 521
Centrifugal type air cleaners 754
Chain Division report 4
Chain, nomenclature for roller 4
Chemical composition of fuels 202
CLARK, W G, ON CARBURETER AIR CLEANERS 745
Clips, rebound, spacers and bolts 17
Cloth type air cleaner obsolete 747
COBURN, COM F G, ON PROBLEMS OF THE NAVAL AIRCRAFT FACTORY DURING THE WAR 304
Commercial future of airplanes from an engineer's standpoint (C H Day) 512
Comparison of airplane and automobile engines (H C Marmon) 146
Comparative pressure-volume diagrams 733
Conditions in the automotive industry abroad (David Beecroft) 669
Connecting-rods, Liberty engine 405
Convoys, seaplane escort for 380
Cooling of cylinder walls 276

Cooling Systems
Liberty engine 413
Modified Class B truck engine 620
Pressure, for radiators 569

Cooling Water
Air bubbles in 566
Mean temperature difference between air and 569
Correct location of brake levers (W C Baker) 657

Costs
Airplane construction and operation 515
First, of hot surface oil engines 692
Records in United States Naval Aircraft Factory 328

Couplings
Flexible disk magneto 7
Magneto 7
CRANE, H M, ON POSSIBLE EFFECT OF AIRCRAFT ENGINE DEVELOPMENT ON AUTOMOBILE PRACTICE 137

Digitized by Google

Crankcases PAGE
Airplane engine 151
Liberty engine 407

Crankshafts
Airplane engine 151
Bearing sizes and loads 635
Liberty engine 404
Load on bearings 635
Size of bearings 635

Crew, location, in airplane 342
CROUCH, G F, ON AUTOMOTIVE APPLICATIONS OF MARINE ENGINES IN THE WAR 112

Cylinders
Angle in Liberty engine 423
Cooling of walls 276
Knocks 210
Liberty engine 408
Reduced weight in 149

Cyclohexane, tests of 213

D

DASEY, P J, ON LUBRICATION AND FUEL TEST ON BUDA TRACTOR TYPE ENGINE 714
DAVIDSON, J B, ON GAS TRACTOR TESTING 504
DAY, C H, ON COMMERCIAL FUTURE OF AIRPLANES FROM AN ENGINEER'S STANDPOINT 512
Dealing with employes 313
DEAN, E W, ON ADAPTING THE FUEL TO THE ENGINE 683
DEAN, E W, ON STATUS OF REFINERY PRACTICE WITH REGARD TO GASOLINE PRODUCTION 229
DE GOLYER, R, ON MEXICO AS A SOURCE OF PETROLEUM AND ITS PRODUCTS 286

Design
Seaplane floats 351
Water pockets in radiators 566

Designing the first aircraft engine 389
Determining airplane performance 348
DICKINSON, DR H C, ON FUEL ECONOMY OF AUTOMOTIVE ENGINES 262
Diesel method of fuel injection 734
Differentials, interlocking, on motor vehicles 78

Dinners
Tractor 491
Victory 34

D'ORCY, LADISLAS, ON CASE FOR THE AIRSHIP 521
Draft of tractors and implements 782
Drawbar horsepower rating 505
Driving gear losses 278

E

Early work of Aircraft Production Board 387
Economy of hot surface oil engines 692

Efficiency
Airplane propeller 346
Brake thermal 270
Fuel, of tractor 89
Overall tractor 88
Securing better engine 218
Volumetric engine 165

Electrical Equipment Division report 6
Elimination of torque and radius rods 624
Engine Division report 5
Engine performance (H L Horning) 602
Engineering, experimental aeronautical (Alexander Klemin) 447

Engines
Adaptability of, to fuel 238
Adapting fuel to (E W Dean and J P Smootz) 683
Air performance of Liberty 425

Digitized by Google

PAGE

Airplane and car service conditions compared 157
Airplane, in automobile 152
Aluminum pistons for high-speed 169
Angle between cylinders in Liberty 423
Applications of high-speed 180
Assembling an organization to produce Liberty 395
Balancing airplane 297
Brake thermal efficiency 270
Builders of marine Diesel 711
Camshaft housing in Liberty 410
Carburetion in Liberty 416
Comparative pressure-volume diagrams 733
Comparison of airplane and automobile (H C Marmon) 146
Connecting-rod in Liberty 405
Constructional details of modified Class B truck engine 617
Controlling factors in design 147
Cooling and lubricating systems in modified Class B truck 620
Cooling of aircraft 302
Cooling of cylinder walls 276
Cooling system in Liberty 413
Crankshafts in Liberty 404
Crankcases in Liberty 407
Cylinder knocks 210
Cylinders in Liberty 408
Demand for fuel 238
Designing first aircraft 389
Diesel 730, 733
Diesel marine, builders 711
Diesel method of fuel injection 734
Diesel, new solid-injection 706
Diesel, present position of, as applied to marine service 701
Driving gear losses 278
Economy of hot surface oil 692
Effect of aircraft, development on automobile practice 137
Exhaust losses 275
First cost of hot surface oil 692
First Liberty completed 397
Fixed radial cylinder (John W Smith) 294
Forced lubrication necessary on high-speed 172
Four stroke constant-volume 726
Friction losses 277
Fuel economy 268
Fuel economy of automotive (H C Dickinson) 262
Fuel consumption in fixed radial cylinder 298
Gernandt method of fuel injection 739
Governor test results 790
High-compression 730
High-compression oil (W G Gernandt) 726
High-speed high-efficiency (D McC White) 162
Hot surface oil, for industrial purposes (A H Goldingham) 689
Hvid method of fuel injection 736
Ignition for high-speed 176
Ignition in Liberty 414
Improvements in airplane 442
Improvements in airplane, not suitable for cars 158
Interpretation of the fuel situation (J E Pogue) 237
Layout work started on aircraft 393
Liberty aircraft (J G Vincent) 385
Lubrication and fuel test on Buda tractor type (P J Dasey) 714
Lubrication of Buda tractor type 718
Lubrication of Liberty 412
McClintock method of fuel injection 738
Marine automotive, applications of 112
Marine Diesel, builders 711
Materials in Hispano-Suiza 142
Mean effective pressures 163
Modified design for Class B truck (A F Milbrath) 616
Mounting of aircraft 300
Muffler losses 278
Multiple valves 166
New solid-injection Diesel 706
Oil consumption in fixed radial cylinder 298
Otto 726, 733
Performance of early motorships 711
Performance with different fuels 604
Pistons in Liberty 406
Propeller-hub in Liberty 407

Digitized by Google

PAGE

Radical changes unlikely 144
Reduced weight in cylinder construction 149
Reliability of hot surface oil 690
Securing better efficiency 218
Size of, for motor trucks 484
Solid-injection, new Diesel 706
Standard type on submarine chasers 126
Standardized Liberty aircraft 401
Sterling type on Italian submarine chasers 135
Substitute fuels 247
Supply of fuel 240, 248
Support arms for trucks 5
Test of Liberty 400
Throttle opening and power 786
Use of all-steel support 618
Useful power 279
V-type 138, 144
Valve gears for high-speed 167
Valve material for high-speed 171
Valve timing in high-speed 168
Van Bierck type on submarine chasers 135
Volumetric efficiency 165
Water-cooled 140
Weight of high-speed 180
Weight of powerplant 296
Weight per horsepower in Liberty 424

Equipment repair truck 62
Error produced by incorrect length of brake rod 662
Escorting convoys 380
Evolution of agricultural machinery 779
Exhaust losses in engines 275
Experimental aeronautical engineering (Alexander Klemin) 447
Eyes, diameter of spring 17

F

Factories of the allied nations, automobile 670
Factors affecting airplane performance 338

Fans

Bearings for cooling 767
Belts for cooling 761
Location of radiator cooling 764
Radiator cooling (George W Hoyt) 758
Size of pulleys for cooling 761

Farm, importance of machinery on 778

Felloe Bands

Dimensions of wood for pneumatic tire rims 26
Edges 27
Tolerances 26

Field of the pneumatic tire 460
First cost of hot surface oil engines 692
First Liberty engine completed 397
Fixed radial cylinder engines (John W Smith) 294
Floats, design of seaplane 351
Forward speed of aircraft in climbing at maximum rate 568
Four-stroke constant-volume engine 726

Friction

Losses in engines 277
Tractor wheel on ground 84

Fuel economy of automotive engines (H C Dickinson) 262

Fuels

Adaptability of engine to 238
Adapting, to the engine (E W Dean and J P Smootz) 683
Available supply of liquid 685
Benzol and alcohol 206
Chemical composition 202
Consumption in fixed radial cylinder engines 298
Demand for engine 238
Development of kerosene and gasoline 266
Diesel method of injection 734

Digitized by Google

PAGE

Distillation curves 207
Economy in engines 268
Economy of automotive engines (H C Dickinson) 262
Efficiency of tractors 89
Engine performance with different 604
Future automotive 263
Gernandt method of injection 739
Hvid method of injection 736
Interpretation of the engine situation (J E Pogue) 237
Liquid, available 685
McClintock method of injection 738
More efficient utilization of (C F Kettering) 201
Oil deposits in Mexico 246
Production of petroleum fractions 684
Properties of petroleum fractions 684
Specific gravity 205
Substitutes for gasoline 247
Supply of engine 240, 248
Supply of liquid, available 685
Test on Buda tractor type engine (P J Dasey) 714
Types derived from petroleum 684

Full-scale methods of testing performance 457
Future development of aircraft 365

G

Gages

Brake-rod 658
Use of brake-rod 659

Gas tractor testing (J B Davidson) 504

Gasoline

Development of, as fuel 266
Production of 241
Recovery of 231
Status of refinery practice with regard to production (E W Dean) 229

Gernandt method of fuel injection 739
GERNANDT, W G, ON HIGH-COMPRESSION OIL ENGINE 726
GOLDINGHAM, A H, ON HOT SURFACE OIL ENGINES FOR INDUSTRIAL PURPOSES 689

Governors

Test results 790
Variable-speed (W W Wells) 784

H

Hedges, Hon Job E, address 34
HEWITT, E R, ON PRINCIPLES OF THE WHEELED FARM TRACTOR 83
High-compression oil engine (W G Gernandt) 726
High-speed high-efficiency engines (D McC White) 162
Hitching plows to tractors 780
Home-coming supper, addresses at 590
HORNING, H L, ON ENGINE PERFORMANCE 602
Hot surface oil engines for industrial purposes (A H Goldingham) 689
Houston, George H, address 43
HOYT, GEORGE W, ON RADIATOR COOLING FANS 758
Hull construction of seaplanes 360
Humidity, control of, in Naval Aircraft Factory 308
HUNSAKER, COM J C, ON NAVAL AIRSHIPS 578
HUNT, O E, ON PROBABLE EFFECT ON AUTOMOBILE DESIGN OF EXPERIENCE WITH WAR AIRPLANES 154
Hvid method of fuel injection 736

I

Ignition

Aircraft and automobile compared 143
Liberty engine 414
Time factor on high-efficiency engines 176

Importance of machinery in farming 778
Inertia air cleaners 748
Influence of brakes in motor vehicles 630
Instruments, tractor testing 507
Interpretation of the engine-fuel situation (J E Pogue) 237

Digitized by Google

PAGE

J

Johnston, Edward A, address 496

K

Kerosene, development of, as fuel 266
Kettering, C F, address 597
KETTERING, C F, ON MORE EFFICIENT UTILIZATION OF FUEL 201
KLEMIN, ALEXANDER, ON EXPERIMENTAL AERONAUTICAL ENGINEERING 447
KRANICH, F N G, ON TRACTOR DRAWBAR IMPLEMENTS AND THEIR HITCHES 777

L

Labor
Policy of Naval Aircraft Factory 313
Training women for aircraft production 312
Working conditions in foreign automobile factories 674

Layout work on Liberty engine started 393
Leaf points 15
Levers, brake, correct location of (W C Baker) 657
Liberty aircraft engine (J G Vincent) 385

Liberty Engine
Air performance of 425
Angle between cylinders 423
Assembling organization to produce 395
Camshaft housing 410
Carburetion 416
Connecting-rod 405
Cooling system 413
Crankcases 407
Crankshafts 404
Cylinders 408
Designing first 389
First, completed 397
Ignition 414
Layout work started 393
Lubrication 412
Pistons 406
Propeller-hub 407
Standardized 401
Tested 400
Weight per horsepower 424

Liquid trap air cleaners 750
LISLE, T O, ON PRESENT POSITION OF THE DIESEL ENGINE AS APPLIED TO MARINE SERVICE 701
Load, effect of, on brakes 661
LOENING, G C, ON MAKING THE AIRPLANE A UTILITY 433
Lubrication and fuel tests on Buda tractor type engine (P J Dasey) 714

Lubrication
Buda tractor type engine 718
Liberty engine 412
Modified Class B truck engine 620
Necessity of forced, for high-speed high-efficiency engines 172

M

McClintock method of fuel injection 738
Machine-gun cars 64

Magneto
Couplings, flexible disk 7
Non-magnetic shims 7

Maintaining production at Naval Aircraft Factory 325
Making the airplane a utility (Grover C Loening) 433
Manly, Charles M, address 40
Marine Diesel engine builders 711

Meetings
Aeronautic at New York City 511
Annual business session 29
Standards Committee 2
Tractor at Kansas City 490

Digitized by Google

PAGE

MARMON, H C, ON COMPARISON OF AIRPLANE AND AUTOMOBILE ENGINES 146
Merrick, H H, address 591
Mexico as a source of petroleum and its products (R De Golyer) 286

Mexico

Bearing of, on fuel situation 246
Petroleum development 289
Petroleum exports 287
Production of petroleum 293

MILBRATH, A F, ON MODIFIED DESIGN OF CLASS B TRUCK ENGINE 616
Miscellaneous Division report 8
Modified design of Class B truck engine (A F Milbrath) 616
More efficient utilizaton of fuel (C F Kettering) 201

Motorcycles

Abroad 681
Pneumatc tires for 27

Motors, barrel-type mounting for starting 6

Motorships

Performance of early 711
Policy of Shipping Board 708

Motor truck chassis design (Cornelius T Myers) 472
Motor truck design, for export 677

Motor Vehicles

Advantages of pneumatic tires 463
Automotive ordnance apparatus (Lieut-Col W G Wall) 59
Bearing sizes and loads, crankshaft 635
Crankshaft bearing sizes and loads 635
Elimination of torque and radius rods 624
Field of pneumatic tires 460
Influence of brakes 630
Interlocking differentials 78
Objections to pneumatic tires 466
Pneumatic tires on trucks (B B Bachman) 459
Progressive and retrogressive designing (O M Burkhardt) 623
Radius rods, elimination of 624
Spring widths and lengths, eye and clip diameters 17
Tire and road surface losses 278
Torque and radius rods, elimination of 624
Two and four-wheel drive 70
Two or four-wheel steer 75

Mount, Finley P, address 491
Muffler losses in engines 278
MYERS, C T, ON MOTOR TRUCK CHASSIS DESIGN 472

N

Naval Aircraft Factory

Atmospheric conditions stabilized 308
Bolt practice 322
Building contracts awarded 305
Construction and design changes 324
Cost records 328
Dealing with employes 313
Engineering department and production 317
Engineering problems at 316
Flexibility in layout 307
How material was obtained 322
Investigating board appointed 305
Maintaining production 325
Original plant 306
Outside contracts handled separately 329
Outside plants and production 310
Problems during the war 304
Problems of enlargement 308
Production increased by engineering department 317
Saving in time 326
Shipping completed planes 323
Source of spruce 323
Special tools and fixtures 324
Training women workers 312

Digitized by Google

PAGE

Utilization of plant 314
Wood defects a problem 320
Naval airships (Com J C Hunsaker) 578
Navy seaplanes, types of 362
No retrogression to pre-war status 434

Nomenclature

Leaf points of springs 15
Roller chain 4
Nuts, machine screw 8

O

Oil shale, development of 227

Oils

Advance in refinery practice 230
Available supply 685
Consumption in fixed radial cylinder engines 298
Geologic investigations 222
Petroleum and its products, Mexico, a source of (R De Golyer) 286
Quantities of different, available 685
Operations of Naval aircraft (Com J H Towers) 373

P

Petroleum

Development in Mexico 289
Geologic investigations 222
Method of producing fractions 684
Mexico as a source of (R De Golyer) 286
Mexico's trade with United States 287
Oil shale, development of 227
Production in Mexico 293
Properties of fractions 684
Relation of production and consumption 225
Types of fuel products derived from 684
Unmined supply in the United States (David White) 220

Patrols

German aircraft 586
Navy aircraft 376
Peake, E E, address 590
Pipes, bends in radiator 560

Pistons

Aluminum and steel, for engines 169
Liberty engine 406
Pneumatic tires on trucks (B B Bachman) 459
Pogue, J E, address 497
POGUE, J E, ON INTERPRETATION OF THE ENGINE-FUEL SITUATION 237
Possibilities of long-distance airship flights 527
Possible effect of aircraft engine development on automobile practice (H M Crane) 137
Post-war foreign car designs 676
Powerplant, location, in airplane 342
Practicability of high airplane speeds 439
Present position of the Diesel engine as applied to marine service (T O Lisle) 701
Pressure cooling system for radiators 569
Principles of the wheeled farm tractor (E R Hewitt) 83
Probable effect on automobile design of experience with war airplanes (O E Hunt) 154
Problems of the Naval Aircraft Factory during the war (Com F G Coburn) 304

Production

Aircraft, aided by outside plants 310
Aircraft radiator considerations 571
Difficulties with United States standard truck 190, 197
Gasoline 241
Gasoline and refinery practice 229
Increased at Naval Aircraft Factory by engineering department 317
Maintaining, at Naval Aircraft Factory 325

Digitized by Google

PAGE

Mexican petroleum 293
Petroleum, and consumption 225
Petroleum fractions 684
Quantity, of United States standard truck begun 195
Progress in airships since 1914 522
Progressive and retrogressive designing (O M Burkhardt) 623

Propellers

Efficiency of airplane 346
Liberty engine hub 407
Pulleys and belts for cooling fans 761

R

Radiator cooling fans (George W Hoyt) 758

Radiators

Adjustment in flight 571
Air bubbles in cooling water 566
Aircraft (Archibald Black) 534
Albatross 539
Bends in pipes 560
British tests 548
Bureau of Standards tests 554
Cooling fans (G W Hoyt) 759
Forward speed of aircraft in climbing 568
Honeycomb 537
Location in aircraft 562
Location of cooling fans 764
Materials employed 570
Mean temperature difference between air and cooling water 569
Miscellaneous 568
Modern aircraft installations 534
Modern types 537
Performance affected by altitude 564
Plate 540
Pressure cooling system 569
Production considerations 571
Shutters 573
Tests by Section Technique Aeronautique 542
Tests for finished 574
Theory 541
Tubular 538
Velocity of air in slipstream 566
Water pockets, design of 566
Weight of 570
Radius rods, elimination of 624
Rail shipment of planes undesirable 323
Rebound clips, spacers and bolts 17
Reconnaissance cars 64
Recovery of gasoline lost at present 231
Reeves, Alfred, address 41

Refinery Practice

Possibilities of advance 230
Status of, and gasoline production 229
Reliability of hot surface oil engines 690

Reports

Standards Committee 2
Treasurer 30
Requirements of good motor-truck design 473
Results of model basin tests compared 357
RICHARDSON, COM H C, ON AIRPLANE AND SEAPLANE ENGINEERING 333

Rims

Dimensions of wood felloe bands for pneumatic tire 26
Valve-hole sizes, automobile 28
Road conditions, effect of, on brakes 661
Roads and highways, power losses on surface 278

S

Safety in landing airplanes 515
Sand tests for airplane surfaces 450

Digitized by Google

PAGE

Screen type air cleaner obsolete 747
Screws, nuts for machine 8

Seaplanes

Airplane and seaplane engineering (Com H C Richardson) 333
Basin tests, results compared 357
Escorting convoys 380
Floats, design of 351
Future development by Navy 365
Hull construction 360
Patrols maintained by Navy 376
Types developed abroad 334
Types of naval planes 362
V-bottom versus the flat 360

Shims, non-magnetic magneto 7
Shipping Board and the motorship 708
Ships, American wooden 703
Shutters for aircraft radiators 573
Size and type of commercial airplanes 518
SMITH, JOHN W, ON FIXED RADIAL CYLINDER ENGINES 294
SMOOTZ, J P, ON ADAPTING THE FUEL TO THE ENGINE 683
Solid-injection Diesel engine, new 706
Solid tires, foreign, mileage 681
Source of spruce 323
Spark-plug, aeronautic, dimensions 13
Specific gravity of fuels 205

Specifications

Leaf spring 19
United States truck, new, prepared 188

Springs Division report 15

Springs

Eye bushings and bolt tolerances 16
Finishes 20
Frame brackets 19
Influence of brakes on load on 630
Leaf point nomenclature 15
Leaf points 15
Leaf, specifications 19
Rebound clips, spacers and bolts 17
Suspension in motor trucks 481
Test for parallelism 15
Width of ends 17
Widths and lengths, eye and clip diameters for commercial vehicles 17
Wrapped eyes 17

Staff observation cars 64

Standardization

Drawbar horsepower rating for tractors 505
Liberty engine 401
United States standard truck 192

Standards Committee report 2
Starting-motor, barrel-type mounting 6
Status of refinery practice with regard to gasoline production (E W Dean) 229
Story of the United States standard truck (J G Utz) 185
Structural strength of airplanes 448

Submarine Chasers

American 110-ft. 118
British M L 112
Engine used 126
Italian 58-ft. 134
Russian 135

Support, all steel engine 618

T

Tanks (H W Alden) 46

Tanks

Armor for 54
Future development 55

Digitized by Google

PAGE

In action 51
Reasons for development of 47
Work done by English 49
Temperature difference between cooling water and air 569

Tests

British radiator 548
Bureau of Standards radiator 554
Cyclohexane 213
Finished aircraft radiator tests 574
Full-scale airplane performance 457
Gas tractor (J B Davidson) 504
Governor 790
Liberty engine 400
Lubrication and fuel for Buda tractor type engine (P J Dasey) 714
Miscellaneous radiator 558
Orange County, N. Y., on wheeled farm tractors 93
Parallelism of springs 15
Sand, for airplane surfaces 450
Seaplane, model basin, compared 357
Section Technique Aeronautique radiator 542
Tractor instruments 507
Wind tunnel, to predict airplane performance 454
Theory of aircraft radiators 541
Throttle opening and engine power 786
Time saving at Naval Aircraft Factory 326
Tire and Rim Division Report 20

Tires

Advantages of pneumatic 463
Base bands for solid 22
Field of pneumatic 460
Industrial truck 20
Mileage secured abroad from solid 681
Objections to pneumatic 466
Pneumatic motorcycle 27
Pneumatic on trucks (B B Bachman) 459
Power loss at 278
Solid, sections 25

Tolerances

Bolt 16
Eye bushings 16
Felloe band 26
Torque and radius rods elimination of 624
TOWERS, COM J H, ON OPERATIONS OF NAVAL AIRCRAFT 373
Track-laying tractors 64, 72
Tractor drawbar implements and their hitches (F N G Kranich) 777
Tractor meeting at Kansas City 490

Tractors

Artillery wheeled 62, 70
Draft of 782
Drawbar implements and their hitches (F N G Kranich) 777
Friction of wheel upon ground 84
Fuel efficiency 89
Gas, testing (J B Davidson) 504
Gear changes 89
Hitching plows 780
Mark VII caisson 68
Overall efficiency 88
Power required to propel 85
Principles of the wheeled farm (E R Hewitt) 83
Size of machine 91
Standard drawbar horsepower rating 505
Testing gas 504
Testing instruments 507
Tests in Orange County, N. Y. 93
Track-laying 64, 72
Weight on wheels 87
Trailers, ordnance 74
Training women employes at Naval Aircraft Factory 312
Treasurer's report 30

Digitized by Google

Trucks PAGE

Advantages of pneumatic tires 463
Ammunition body 59
Artillery repair and supply 60, 62
Automotive Ordnance apparatus (Lieut-Col W G Wall) 59
Caterpillar track adapters 76
Chassis design (C T Myers) 472
Conference on United States, first 186
Cooperation of S A E on United States standard 199
Design of motor, for export 677
Design of United States standard begun by War Department 194
Engine support arms for 5
Equipment repair 62
Field of pneumatic tires 460
Industrial, tires 20
Industrial, wheel base bands 25
Modified design of engine for Class B (A F Milbrath) 616
Nash and F W D 59
New specifications for United States, prepared 188
Objections to pneumatic tires 466
Pneumatic tires on (B B Bachman) 459
Production difficulties with United States 190, 197
Quantity production of United States standard, begun 195
Requirements for good motor 473
Service of United States standard, in France 198
Size of engine 484
Spring suspensions 481
Standardization 192
Tires for industrial 20
United States standard (J G Utz) 185

U

United States Government

Army—
War Department, design of United States standard truck begun 194
Navy—
Airplane and seaplane engineering (Com H C Richardson) 333
Naval airships (Com J C Hunsaker) 578
Operations of Naval aircraft (Com J H Towers) 373
Problems of the aircraft factory during the war (Com F G Coburn) 304
Shipping Board—
Policy regarding motorships 708
Unmined supply of petroleum in the United States (David White) 220
Use of all-steel engine support 618
Useful power of engines 279
UTZ, J G, ON STORY OF THE UNITED STATES STANDARD TRUCK 185

V

V-bottom versus the flat 360

Valves

High-speed engine gear 167
Material for high-speed engine 171
Multiple for engines 166
Timing for high-speed engines 168
Variable-speed governors (W W Wells) 784
Velocity of air in slipstream 566
VINCENT, J G, ON LIBERTY AIRCRAFT ENGINE 385

W

WALL, LIEUT-COL W G, ON AUTOMOTIVE ORDNANCE APPARATUS 59
Water pockets, design of radiator 566

Weight

Aircraft radiator 570
Airplane engine 296
High-speed engines 180
Liberty engine, per horsepower 424
WELLS, W W, ON VARIABLE-SPEED GOVERNORS 784

Digitized by Google

Wheels PAGE
Base bands for industrial truck 25
Friction of tractor, ground 84
Weight on tractor 87
WHITE, DAVID, ON UNMINED SUPPLY OF PETROLEUM IN THE UNITED STATES 220
WHITE, D McC, ON HIGH-SPEED HIGH-EFFICIENCY ENGINES 162
Willys, John N, address 39
Wind tunnels, airplane performance predicted from tests in 454

Wings
Effect of size on airplane performance 339
Form and proportion of airplane 344
Wood defects a problem 320
Working conditions in foreign automobile factories 674

Z

Zeppelin airships 582

Digitized by Google

Digitized by Google

Digitized by Google

Digitized by Google

89045755584

b89045755584a

Digitized by Google

Digitized by Google

89045755584

b89045755584a

Digitized by Google